Water Quality Monitoring with Ubiquitous Computing

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Abstract—**Traditionally, data collected from water quality monitoring systems are typically stored in closed repositories that are not shared with the public. Due to the cost and environmental limitations traditional water quality monitoring systems cannot collect sufficient samples to reflect the overall status of water quality. In this paper, the monitored data were transmitted in real time by WCDMA to the central server via a 3G network. In such a ubiquitous environment every user can interact with other mobile users or devices. Next, grey relational analysis is used to find the most influential water factors that help us easily realize the overall status of water resources. Experimental results verify the applicability of the proposed ubiquitous system.**

Keywords-Remote sensing; WCDMA; Ubiquitous information center; Water monitoring; Grey relational analysis

I. Introduction

Traditional water quality monitoring systems use monitoring instruments to measure and store data regularly. Researchers must manually download data from storage media to their computers when analyzing data. This process is time-consuming and data cannot be sent immediately to the central server for further analysis. Since the globally rapid development of mobile communication technology, the transmission rate of GSM, GPRS, and the currently popular 3G networks has been greatly enhanced. This allows mobile phone users to watch online films and browse web pages with their mobile devices. Similarly, we can use mobile communication networks to transmit monitored data at great distance. For example, data acquired at lakes or fish farms can be sent to the central server and stored in a database for real time analysis. Using 3G networks, we can use the concept of ubiquitous computing for multi-platform communication between people.

In the water quality monitoring literature, Ribeiro et al. [9] reviewed some applications of real time water quality monitoring system. Ribeiro et al. [11] used a satellite with chlorophyll concentration and neural network to predict status of lakes and reservoirs. Postolache et al. [14] used GPRS and a Kohonen SOM (Self organizing Map) to monitor water quality in real time. Brockmann and Stelzer [20] introduced water quality monitoring of coastlines. Wang et al. [21] deployed Zigbee technology to construct water monitoring system.

There are many uncertainties in outdoor environments that result in the lack of data collection. Therefore, grey theory is applied to conduct analysis with insufficient data. Grey relational analysis uses a discrete method to find relationships among factors that exerts on the system. Based on the relative relational degrees, we can find the most influential factors in the system.

In this study, we used Winsock to provide Internet service and constructed a server to receive monitored data from client-side programs. The client-side receives data from water monitoring instrument via an RS232 serial link, and then transmits packaged data to server. We developed a ubiquitous information center for end users such as researchers, school teachers, and general users. Researchers and general users can request monitored data from ubiquitous information centers with their mobile phones, laptops, or any mobile devices anytime and anywhere. Users can interact with touch display system for understanding the current situations of lakes, fish farms, etc. Finally, we used the data collected at the National Taipei University of Technology fish pond as case study to proceed with multiple-variable monitoring model by using grey relational analysis.

II. Related Work

This section describes the architecture and related concepts for the proposed system, and briefly outlines grey relational analysis and the meanings of water quality factors.

A. Ubiquitous computing

Ubiquitous computing was proposed by Weiser in 1991 [18] as "Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence". This means that we can use powerful computing technology with limited awareness of computers, servers, and other devices. Thus, it depends on many technologies such as wireless networks, distributed systems, embedded systems, mobile communication, artificial intelligence, service-oriented computing, micro-electromechanical systems, and human-computer interaction. Ubiquitous computing can be summarized as follows [15]:

(1) Computers need to be networked, distributed and transparently accessible.

(2) Human–computer interaction buttons need to be simple and visible.

(3) Computers need to be context-aware in order to be optimized for their operation in their environment.

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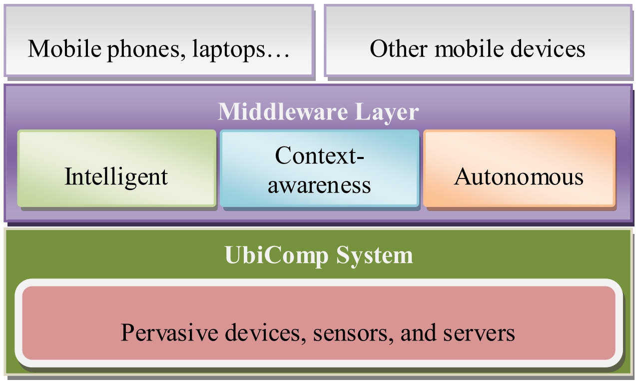

Figure 1. A ubiquitous computing system architecture.

(4) Computers can operate autonomously, without human intervention and be self-governed.

(5) Computers can handle a multiplicity of dynamic actions and interactions, governed by intelligent decision-making and intelligent organizational interaction.

Fig. 1 shows the general ubiquitous computing architecture and how people interact with middleware to obtain and use calculated result and other information.

1) Human computer interface

To design a user friendly system, we used 5W1H (When, Where, Who, What, Why and How) to build our user interface.

Who is the user? Fish farmers, researchers, and environmental officers may use our system to protect fish farms or the environment. Therefore, we focus on these user domains to build a suitable user interface. For example, the system only displays basic cultivating information to fish farmers and detailed data to researchers. Thus, users obtain relevant information for their specific tasks.

Where is system used? This system can be applied to lakes, rivers, fish farms, etc. The system will deliver an alarm signal to users when there are abnormal data detected in specialized places.

Why are we developing the system? Since some monitoring locations are located in remote areas such as mountains or ocean regions, it is hard to retrieve monitored data from different locations. Therefore, we developed this system to retrieve monitored data easily by using wireless network technology.

When is the system used? According to the habits and lifestyle of users, the system sends updated information to users. Therefore, users can realize the updated status about their fish farms or monitored regions.

What are the users' needs? Users may for instance wish to know the current status of their fish farms. Researchers may wish to analyze historical data.

How the system is to work? We can take users' feeling about the system to improve the user interface and modify the operational procedures of the proposed system.

2) Ubiquitous middleware

Ubiquitous middleware [16], [19], [22] is the communicative bridge between services and ubiquitous devices or sensors. Its roles include data access, cooperation of devices, context awareness, etc. Recently, biometric technologies are integrated into the middleware. For example, human fingerprints and voiceprints are used to recognize authentication that can save typing effort for users.

In the proposed case, the server-side is used as middleware and the client-side is used as the ubiquitous device. When receiving monitored data from the water quality sensors, the client-side transmits them to the server-side. When the server-side receives data from the client-side, it calculates and estimates the water quality. It signals alarms to users if anomalies are detected. The server-side also interacts with users who are using mobile phones, laptops, or other mobile devices.

B. Wireless network technology

Currently there are a variety of wireless network technologies, and different technologies generally represent different coverage and transmission rates. The following paragraphs describe selected mainstream communication technologies:

IMT-2000: International Mobile Telecommunications-2000 [1], [4], also known as 3G or 3rd Generation. It was established by International Telecommunication Union (ITU), and four 3G network standards exist: EDGE, CDMA2000, UMTS, and DECT. ITU has not provided a clear definition of the data transmission rate, but the theoretical transmission rate in Taiwan is 384 Kbps.

3G is the next generation mobile communication technology that combines wireless communication and Internet multimedia. It can handle music, pictures, and video and supports web browsing, video conference and more. If users stay at different locations, the 3G network switches to different transmission rates suitable for the given situation. That means, if users stay inside, outside, or in a moving vehicle, the rate will be 2Mbps, 384Kbps, 133Kbps, respectively.

HSDPA: HSDPA is an abbreviation of High Speed Downlink Packet Access, also known as 3.5G. It proves the same download bandwidth as ADSL. 3.5G is enhanced from 3G network technology and ideal transmission rates include 3.6Mbps, 7.2Mbps, and 14.4Mbps. If handheld devices or laptops have build-in or external HSDPA network interface cards users will be able to enjoy 3.5G network anytime and anywhere.

WiMax: WiMax is an abbreviation for Worldwide Interoperability for Microwave Access [17], and it is a high speed wireless network standard. Theoretically, WiMax coverage is wider than the 3G network and can reach as far as 50 km with a maximum transmission rate of 70 Mbps.

TABLE I. COMPARISON OF WIRELESS NETWORKS

Technology	WCDMA	HSDPA	WiMax
Maximum rate	2Mbps	14.4Mbps	70Mbps
Coverage	0.5~10Km	0.5~10Km	50Km

1) Comprehensive comparison of wireless networks

In summary, different locations need to adopt different wireless technologies to solve remote sensing problems. The monitoring program only needs connection to the server. Thus, it can easily transmit data to a server via 3G network. Table I compares different wireless network technologies.

C. Water quality factors

Potential for hydrogen ion concentration (pH): It represents the concentration of hydrogen ion in water. In general the range of pH values is between neutral and alkalescent. For organisms, safe pH values are between 6.5 and 8.5. When water is contaminated and the value of pH value is changed, it will result in a decrease in biological productivity or even cause death.

Dissolved oxygen (DO): It represents the concentration of air or oxygen released by photosynthesis of aquatic plants dissolved in water. The increase of water temperature will result in lower DO values in water. Contaminated water will cause microorganism consuming excessive oxygen and result in aquatic life to die. Therefore, a high oxygen concentration is desirable.

Conductivity: This factor is the amount of conductive material in the water. More dissolved ions have higher conductivity with common ions H+, Na+, Ca2+, etc. Generally, freshwater have conductivity values less than 1200 µS/cm. The conductivity can be used as a measure of contamination.

Turbidity: It refers to the obstructive degree of light through water with suspensor. Usually they are dust, sand, and plankton. If light cannot penetrate the water, aquatic plants are unable to perform photosynthesis and fish will die due to asphyxia.

Water temperature: It represents degree of temperature of water and it is an important factor to evaluate water quality. The variation of DO value usually is caused by seasonal changes.

Salinity: The salinity of water contains. The salinity also affects DO value of water with the higher salinity causing the lower DO value. When a body cannot regulate the balance of osmotic pressure, the organisms will be sick and easily die.

Total dissolved solids (TDS): The last factor is the total concentration of dissolved organic and inorganic salt in water. TDS is related with conductivity when the higher conductivity results in higher TDS values. More ions dissolved in water will lead to better conductivity. That is, high TDS values indicate that there are impurities in the water.

D. Grey relational analysis

Grey system theory [6], [7] is mainly aimed at the system model of uncertain and incomplete information. The grey model avoids inherent defects of conventional models and only requires a limited amount of data to estimate the behavior of uncertain system. In summary, the main purpose of grey system theory focuses on the relation between the analysis model construction, and four circumstances such us: no certainty, multi-data input, discrete data, and insufficient data through predicting and decision-making [12]. In this paper, we calculate grey relational grades from factors to compare their relative importance to the system.

The grey relational grade is the most important topic in relational analysis [2], [8], [13]. The main function is the measurement between two discrete sequences, and the result is the objective weighting in the system.

In order to investigate the association between various factors, first, all factors need to be integrated into a factor set. In making sequence comparisons, we need to select a sequence as a comparison standard, called the reference sequence. In contrast, the others that are compared with the reference sequence are called the comparative sequence. Finally, if we take only one sequence as the reference sequence, and the other sequences as inspected sequences, then, it is called the localization grey relational grade. If each sequence can be the reference sequence, then, it is called the globalization grey relational grade. This study adopted globalization grey relational grade on the importance of environmental factors affecting water quality. The mathematical foundation of grey relational grade is described in the next section.

1) Grey relational grade

When a space is formed by satisfying factor space and comparability, the space is called a grey relational space and is denoted by $\{p(x);\Gamma\}$, where $\{p(x)\}$ is the measured data and Γ is the metrics. Assume a sequence as $x_i(x_i(1), x_i(2), \ldots, x_i(k)) \in X$, $i=0,1,2,\ldots, m$, $k=1,2,3,\ldots,n \in N$, i.e.,

$$\begin{aligned} x_1 &= (x_1(1), x_1(2), \ldots, x_1(k)) \\ x_2 &= (x_2(1), x_2(2), \ldots, x_2(k)) \\ x_3 &= (x_3(1), x_3(2), \ldots, x_3(k)) \\ &\vdots \\ x_m &= (x_m(1), x_m(2), \ldots, x_m(k)) \end{aligned} \quad (1)$$

and meet the following three conditions: non-dimensional, scaling and polarization.

In the definition of globalization grey relational grade, each sequence can be the reference sequence. Because the grey relational grade proposed by Deng and Wong is an ordinal form [3], there did not exist any globalization grey relational grade. In our research, we use Wen's method [10] to obtain the grey relational grade.

(1) Wen's globalization grey relational grade

$$\Gamma_{ij} = \Gamma(x_i, x_j) = \frac{\Delta_{\min.} + \Delta_{\max.}}{\bar{\Delta}_{ij} + \Delta_{\max.}}, \text{ where } \bar{\Delta}_{ij} = \left\{ \frac{1}{n} \sum_{k=1}^{n} \left[\Delta_{ij}(k) \right] \right\} \quad (2)$$

In the globalization grey relational grade, we treat each sequence as the reference sequence and the others as the to-be-inspected sequences. By calculating all the grey relational grades, we can construct a relative weighting matrix which is called the grey relational matrix.

$$R_{m\times m} = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1m} \\ \gamma_{12} & \gamma_{22} & \cdots & \gamma_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{m1} & \gamma_{m2} & \cdots & \gamma_{mm} \end{bmatrix} \tag{3}$$

To find the relational degrees, the procedures are stated below.

(1) Constructing the relative weighting matrix $[R]_{m\times m}$.

(2) Finding the eigenvalue for the relative weighting matrix:

$[R]_{m\times m}$: $AR = \lambda R$.

(3) Using eigenvector method to find the weighting for each target

$P^{-1}RP = diag\{\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n\}$

(4) The maximum λ corresponding eigenvector is the weighting value for the whole sequences.

The weights in the grey relational matrix that are listed in the main diagonal elements in the system share the importance of the appraisal, which is the size of the matrix that can be used as a guideline for determining the influential factors in the system.

III. Experimental Results and Analyses

We used a hand-held water quality monitoring meter (WQC-24) which is produced by TOADKK Corporation in our experiments. It can detect water quality factors such as pH, DO, conductivity, salinity, TDS, sea water specific gravity, water temperature, turbidity, and some salt ions. The client-side receives data from WQC-24 via an RS232 link, displays received data on the screen and then transmits them to the server. Fig. 2 shows the WQC-24. Fig. 3 depicts the architecture for real time water quality monitoring system.

Figure 2. Water quality meter (WQC-24).

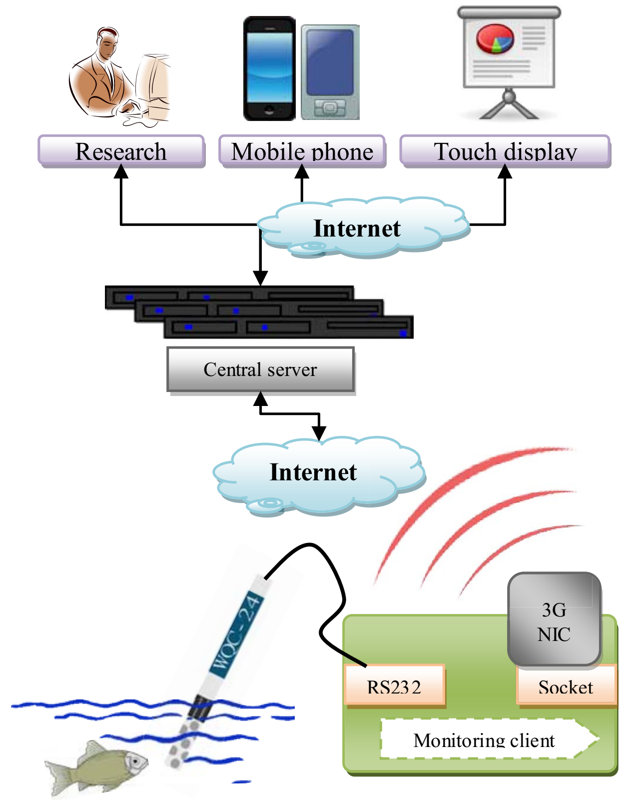

Figure 3. The proposed system archtecture.

TABLE II. Details of Software and Hardware Requirements

A. Experimental environment

	Software	Description
1	Visual Studio C# Express 2008	For writing server and client programs
2	MySQL 5.1.45	Saving received data from client
	Hardware	**Description**
1	WQC-24	Hand-held water quality meter
2	3G network card	Connect to 3G network

In this study, we used Microsoft Visual C# 2008 for writing both server-side and client-side programs, and a MySQL database for saving received data from client-side. A 3G network and Winsock are used for communication between the server and the client. Table II lists details of software and hardware requirements.

B. Data collection and analysis

The proposed system is deployed for long-term monitoring of the water quality in the fish pond. Our experimental data were collected using WQC-24 at the National Taipei University of Technology fish pond. While monitoring the fish pond, the client-side program transmitted monitored data to NTUT Ubiquitous Computation Laboratory and data were stored in a MySQL database. The required measurement instruments of the proposed water quality monitoring system

(a) (b)

Figure 4. Instruments of water quality monitoring system.

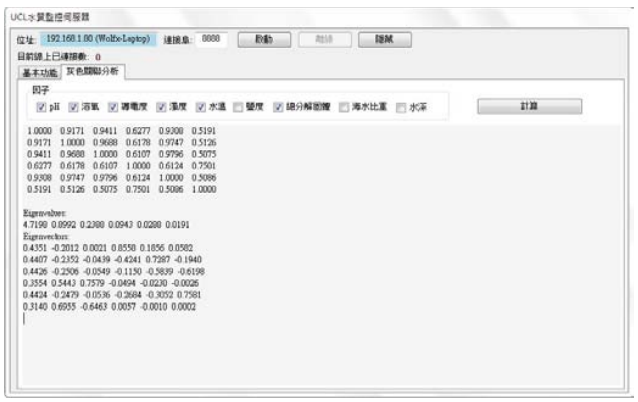

Figure 5. Results of grey relational analysis.

are shown in Fig. 4(a), including a laptop with 3G network card for real time transmission of data to the central server. Fig. 4(b) shows the WQC-24 working situation in the fish pond. And Table III shows part of water monitoring data which are recorded once per minute.

We use grey relational analysis for analyzing water quality data and focus on pH, DO, conductivity, turbidity, water temperature, and TDS. We took 205 records collected during a two day interval between April 21~22, 2010 as an example and applied grey relational analysis to pick the influential factors among candidate factors. Fig. 5 shows the results and Table IV shows the eigenvector calculated with our experimental data. The results indicate that the most influential factors sorted in decreasing order are conductivity (0.4426)> water temperature (0.4424)> DO (0.4407)> pH (0.4351)> turbidity (0.3554)> TDS (0.3140). It means that the conductivity is the most influential factor. Among these factors, the values of TDS are almost 0, and are thus omitted in subsequent analyses.

IV. Conclusion and Future Work

In the past, water quality monitoring instruments only transmitted data to the monitoring station in the vicinity of the measurement instruments. Therefore, every monitoring station was required to install its own server and instruments. In this paper, we use wireless network such as 3G network or WiMax for transmitting data to the server. A server can also function as a ubiquitous information center, and then we can use mobile devices to communicate with the server for obtaining useful information. Grey relational analysis is applied for determining the most influential water quality factors that are in turn used as reference to improve contaminated situation and reduce impact on ecology in water. The proposed system not only reduces the requirement of device deployment, but also reduces the server heat generated by continuing operations to achieve carbon reduction effect.

Future work includes the integration of the proposed system with a large-scale touch display system to show real time data and their meaning to the public. Users can then interact with our system and teach children the meaning of environmental protection and play using educational and entertaining games.

TABLE III. Water Monitoring Source Data

Date	pH	Do	Cond.	Turb.	Temp.	TDS
2010/4/21 14:05	6.83	6.61	10.2	3.1	24.2	0
2010/4/21 14:06	6.84	6.58	10.2	2.6	24.2	0
2010/4/21 14:07	6.84	6.58	10.3	3.6	24.2	0
2010/4/21 14:08	6.84	6.57	10.3	2	24.2	0
2010/4/21 14:09	6.84	6.56	10.3	2	24.2	0
2010/4/21 14:10	6.84	6.56	10.3	1.9	24.2	0
2010/4/21 14:11	6.84	6.56	10.3	1.9	24.2	0
2010/4/21 14:12	6.84	6.56	10.3	1.4	24.2	0
2010/4/21 14:13	6.84	6.57	10.4	1.6	24.2	0
2010/4/21 14:14	6.84	6.57	10.4	1.7	24.2	0

TABLE IV. Eigenvector of Grey Relational Analysis Result

pH	0.4351	-0.2012	0.0021	0.8558	0.1856	0.0582
Do	0.4407	-0.2352	-0.0439	-0.4241	0.7287	-0.1940
Cond.	0.4426	-0.2506	-0.0549	-0.1150	-0.5839	-0.6198
Turb.	0.3554	0.5443	0.7579	-0.0494	-0.0230	-0.0026
Temp.	0.4424	-0.2479	-0.0536	-0.2684	-0.3052	0.7851
TDS	0.3140	0.6955	-0.6463	0.0057	-0.0010	0.0002

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