Songklanakarin J. Sci. Technol.
33 (2), 227-235, Mar. - Apr. 2011

SJST SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

Original Article

Real-time flood monitoring and warning system

Jirapon Sunkpho*[1] and Chaiwat Ootamakorn[2]

[1] *School of Engineering and Resources, Walailak University, Thasala, Nakhon Si Thammarat, 80160 Thailand.*

[2] *National Science and Technology Development Agency, Klong 1, Klong Luang, Pathum Thani, 12120 Thailand.*

Received 15 December 2010; Accepted 29 March 2011

Abstract

Flooding is one of the major disasters occurring in various parts of the world. The system for real-time monitoring of water conditions: water level; flow; and precipitation level, was developed to be employed in monitoring flood in Nakhon Si Thammarat, a southern province in Thailand. The two main objectives of the developed system is to serve 1) as information channel for flooding between the involved authorities and experts to enhance their responsibilities and collaboration and 2) as a web based information source for the public, responding to their need for information on water condition and flooding. The developed system is composed of three major components: sensor network, processing/transmission unit, and database/ application server. These real-time data of water condition can be monitored remotely by utilizing wireless sensors network that utilizes the mobile General Packet Radio Service (GPRS) communication in order to transmit measured data to the application server. We implemented a so-called VirtualCOM, a middleware that enables application server to communicate with the remote sensors connected to a GPRS data unit (GDU). With VirtualCOM, a GDU behaves as if it is a cable directly connected the remote sensors to the application server. The application server is a web-based system implemented using PHP and JAVA as the web application and MySQL as its relational database. Users can view real-time water condition as well as the forecasting of the water condition directly from the web via web browser or via WAP. The developed system has demonstrated the applicability of today's sensors in wirelessly monitor real-time water conditions.

Keywords: sensors, real-time monitoring, flood control

1. Introduction

Flood becomes one of the major problems in most of the countries around the world. Although, we are able to forecast rainfall or to track storm path very precisely from the satellite images, the need to have real-time monitored data such as flow, precipitation level, or water level is essential in order to make a reasonable decision on the actions necessary to be performed to prevent flooding. In Nakhon Si Thammarat, a southern province in Thailand, flooding is a recurrent event affecting the entire province, especially the urban area. Every year, it causes lives and damages to infrastructure, agricultural production and severely affects local economic development. Over the past ten years, high volume removal, extensive area cut, and intrusion of communal forest, in addition to ineffective protection of cut-over forest, has accelerated the increasing need to address the flood hazard in the urban region. Because of the significant reduction of the forest, the flood peak may travel more rapidly to produce higher risks within the short lead times in populated areas. The problems also include unpredicted heavier local rainfalls and insufficient drainage capacity, which cause household water logging. For example, in November 2002, the flash flood caused deaths and the estimated total loss of more

* Corresponding author.
Email address: sjirapon@wu.ac.th

than ten millions Thai baht for the Nakhon Si Thammarat urban area only. Flood also jeopardizes low area and/or bay area in the province. As a result, flood management of the province is a crucial challenge. Local authorities and experts need to access a vital infrastructure system that is able to provides accurate, reliable, timely flood-related information and timely warnings to assist them respond to flood events. Flood monitoring using real-time sensor is one of the non-structural flood control measures. Losses due to flooding can be reduced by means of measures such as monitoring, forecasting, simulation, evaluation, and analysis (Chen, 1990; OAS, 1990; UNDRO, 1991). One nonstructural measure, the integrated use of wireless sensors and web-based decision support system has been playing a very important role in monitoring, controlling, relieving, and assessing natural disasters, especially flood disaster (Zhang, 2002; Sapphaisal, 2007).

The effective implementation of flood monitoring and warning system is non-trivial, since it requires the reliability coupled with the availability of related information. Over the years, flooding has been studied under various considerations and methodologies such as wireless sensors network (Chang, 2006; Hughes, 2006; DeRoure, 2005), embedded system with a middleware (Hughes, 2006; Chen, 1990), Internet-based real-time data acquisition (Chang, 2002), and flood modeling and forecasting (Creutin, 2003; Sapphaisal, 2007; Zhang, 2002). In addition to sensor technologies, space and satellite data technologies has been used to improve the accuracy (Manusthiparom, 2005; Veijonen, 2006; Louhisuo, 2004). These papers provide great insights into the development of flood forecasting and modeling using satellite data, image processing, and GIS. One of the widely used infrastructures in order to build a flood monitoring and warning system is an ad-hoc wireless sensor network (Chang, 2006; Hughes, 2006; DeRoure, 2005). In ad-hoc network, a monitoring system can be decomposed into a set of remote wireless communication systems, which log water condition data, and transfer the data to a web-based information center to build a real time Internet–based flood management system. This concept was employed in this research work.

Chang (Chang, 2006) uses the flood monitoring network that relies on small wireless sensor platform, called MICA (Crossbow Technology, 2007). This device has a quite low-speed CPU with extremely modest power requirements, i.e., it consumes only 54mW during active operation allowing long periods of operation with small batteries. However, with such a small power, the device has some limitations on processing power to provide complex functionalities, such as on-site data processing for flood prediction, and on networking coverage area. In our case, we have to build a wireless sensor network in a very large area for distribution of flood data and warnings. In order to achieve this, we exploit the GPRS communication as the core networking infrastructure as proposed in (Hughes, 2006; DeRoure, 2005; Rodden, 2005). In the GPRS network, the communications are not limited by range. Some of research works (Hughes, 2006; DeRoure, 2005) employs grid-based network in their studies. Another vital example of utilizing the grid-based wireless sensor network is presented in (Rodden, 2005). It is shown that the schemes proposed by Hughes *et al.* (Hughes, 2006) can be performed by remote sensors; therefore, the local processing power can be employed to provide flood-related computations. The key difference between our work and the work by Hughes' and Chang's is that we implemented the system as a non-grid-based wireless sensor network with a GPRS-tunnel middleware, thus, enables remote sites with any types of sensors to communicate in the network. As a result, our approach does not have the flexibility and scalability problem since the designed a GPRS-tunnel middleware does not depend on the underlying network domain. Finally, in order to provide real-time flood condition information and timely flood warnings to stakeholders, a web-based decision support system for flood management is usually employed (Chang, 2002). Our work also provides real-time flood condition by using database and web service application server at a control center. In addition, we exploit the data processing based on the results of point prediction model to trigger timely warnings (Short Message Service (SMS), FAX, and Email) to stakeholders.

This paper illustrates a new tailored wireless sensor network. The network is aimed to be the base on which to construct a regional system (a wireless Sensor Network) for distribution of flood data and warnings. The wireless sensor network is composed of one or more instances of the flood monitoring devices at 15 remote sites located around the flood-risk area in Nakhon Si Thammarat. We develop the network with an Internet-based real time monitoring, visualization, forecasting, and warnings. It can provide real-time crucial flood-related information and broadcasting functionalities to different levels of federal, state, and local agencies, as well as local communities. The network utilizes the long-range mobile GSM communication to provide data communication continuity. The developed system is composed of three major parts: sensor network, data transmitting and processing, and database and application server/computer. The number of nodes and base stations (GPRS Data Unit: GDU) and particular sensors is deployed at the 15 different locations. The installed sensors were installed to measure water level, flow level, and precipitation level. We employ STARFLOW sensor to measure water level/flow and the precipitation sensor by Fischer, which employs a tipping bucket rain gauge system, to monitor precipitation data. These measured data were then sent to the server by the data transmitting and processing module which employs GPRS network in sending the measured data to the application server. The key function in data transmission is that we employ a so-called VirtualCOM, a middleware that enables application server to communicate with the remote sensors connected to a GPRS data unit (GDU). With VirtualCOM, a GDU behaves as if there is a cable directly connected the remote sensors to the application server. The database and application server has the functionalities of processing the measured data in real-time and make them accessible online via either web browser or WAP-enabled mobile phone.

This paper is organized as followed. The overview of the case study of implementing flood monitoring system in Nakhon Si Thammarat is presented first followed by the overview of the system implementation of sensor network, processing/transmission module, and the database and application server. Finally, the discussion of the advantages of the system as well as the future direction is illustrated in summary and conclusion section.

2. Case Study

The case study presented in this paper is a wireless flood monitoring system for Nakhon Si Thammarat, a province in the south of Thailand. The objective of this monitoring system is to make use of remote sensing data in the operative process of early warning, mitigation and management of flood disasters in the flood area (urban and suburban) shown in Figure 1. The system is designed to monitor crucial flood-related information (Water level, flow, and precipitation) and then trigger timely warnings (Short Message Service (SMS), FAX, and Email), in case of flood, to be distributed to local stakeholders. These flood warnings are based on the results of point prediction model, called warning profiles. As a result, the communicational function of the system has two main advantages. It serves as information channel between the involved authorities and experts in their task of producing and sharing up-to-date information of the flooding. The second is that the system serves as a web based information source for the public, responding to their need for information on water condition and flooding.

The system is aimed to be a base on which to construct a regional system (a wireless Sensor Network) for distribution of flood data and warnings. The wireless sensor network is composed of one or more instances of the flood monitoring devices at 15 remote sites located around the flood-risk area in Nakhon Si Thammarat (see Figure 1). Due to the reliability- and safety-critical nature of this application, the arising main challenges are 1) data communication continuity, which can be severely affected by the remote environment and locations, and 2) sensor functionality and implementation, which can be obstructed by the water hostile environment. In this paper, we illustrate a new distributed wireless sensor network using the long-range communication (e.g., mobile GSM network). We developed an Internet-based real-time monitoring, visualization, forecasting, and flood profiles in these suburban and urban flash flood events. The developed system provides end users web information broadcasting functionalities to build a real-time internet–based suburban and urban flood management system. Users of this vital infrastructure system may include different level of federal, state, and local agencies, as well as local communities. With the implementation of such a customized sensor network system, monitored information will be available to users in real time, without geographical and weather constraints, through the web via multiple wireless communication systems.

3. System Overview

In this section, we describe the overview of the system implemented. We first describe the system architecture and followed by discussion of the implementation of the sensor

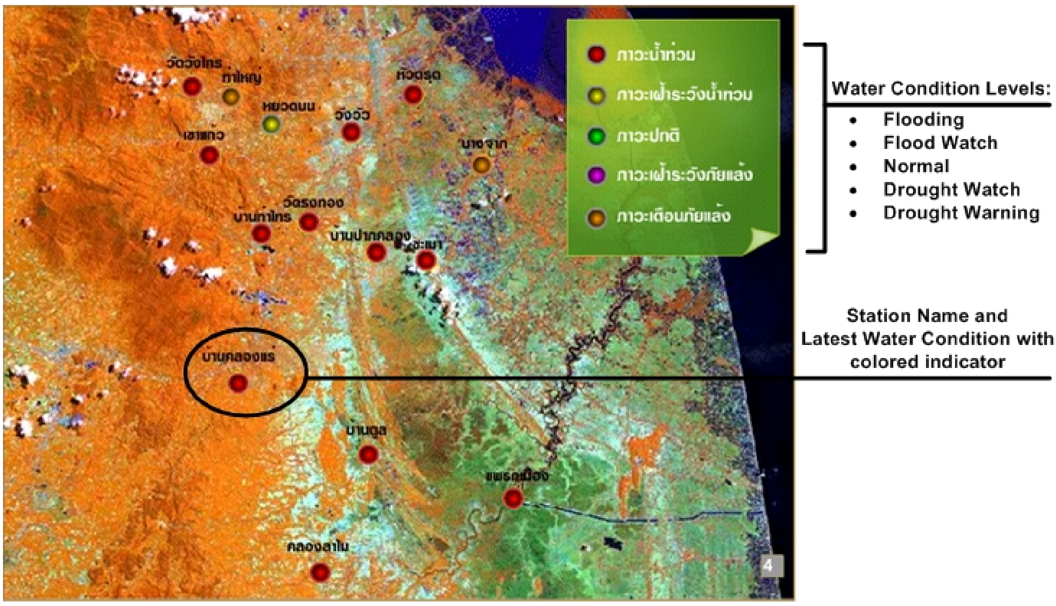

Figure 1. Nakhon Si Thammarat LANDSAT (the flood-risk area) and the 15 remote sites

network. Finally, the implementation of the data transmitting and processing unit and the database and application server are described.

3.1 System architecture

In this section, we describe the underpinnings of the proposed flood monitoring system of using remote sensing to support the real-time and reliable data acquisitions. The system architecture can be illustrated at the highest level in Figure 2. The system consists of three major modules. The first module (Monitoring Sensors) includes our customized sensors for measuring water level, flow, and precipitation. The second module is the data transmission and processing module, of which each resides at the remote sites and the control center in order to enable the control center to communicate with the remote sensor devices as if they are directly connected by a cable. In fact, the data goes through mobile General Packet Radio Service (GPRS) tunnel. The data processing and transmission module installed at a remote site is a GPRS Data Unit (GDU) while the GPRS gateway server is implemented at the control center. The third module runs as a database and application server/computer, which has the functionalities to process the three types of information in real-time and make them accessible online. That is, the system is implemented as a web-based application that provides users with views of water condition. End user can access this system through web browser (Internet) or Mobile devices (WAP: Wireless Application Protocol).

In order to handle various types of data at a remote site, we employ a GDU manufactured by NXN Technology (NXN 2007) to support both computing and communication capabilities. The GDU has a data logger of 2MB memory, which can be used to store monitored data when the communication is unavailable. In addition, Global Positioning Systems (GPS) is included in the unit in order for the unit to automatically provide the location information. The application of GDU represents a new and potentially powerful tool in flood monitoring. The challenges in the successful application of GDU are the development of a monitoring system that enable many GDUs that spread across a long distance to communicate to the control center in a timely, efficient, and robust manner. There is an API-based application installed at the control center to manage and organize a set of GDUs in the 15 various locations as shown in Figure 1.

3.2 Monitoring sensors

In Figure 3, we show the structure of each monitoring sensor unit at a remote site. In monitoring sensor module, we employ 1) an ultrasonic Doppler instrument with a 128K data logger, called STARFLOW, manufactured by UNIDATA (UNIDATA 2007), Australia, to monitor water level and velocity (See Figure 4) and 2) a precipitation sensor by Fischer (MetoClima 2007) to measure the amount and intensity of rain (See Figure 5). STARFLOW is deployed under

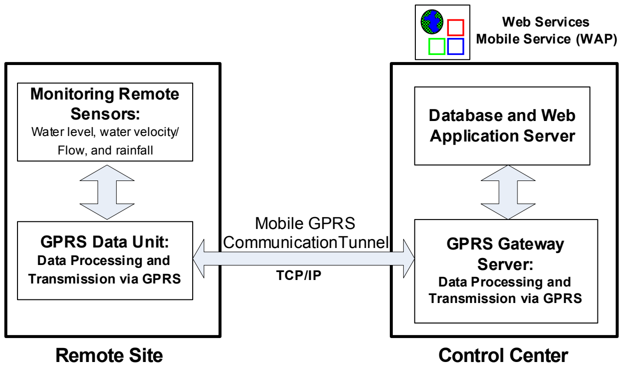

Figure 2. The highest-level system architecture.

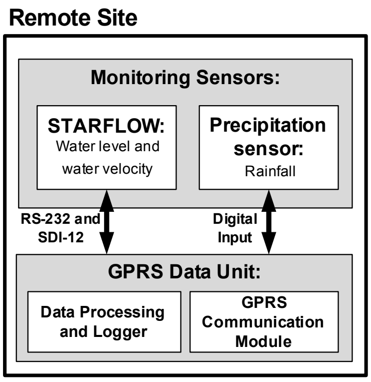

Figure 3. The structure of water monitoring unit at a remote site.

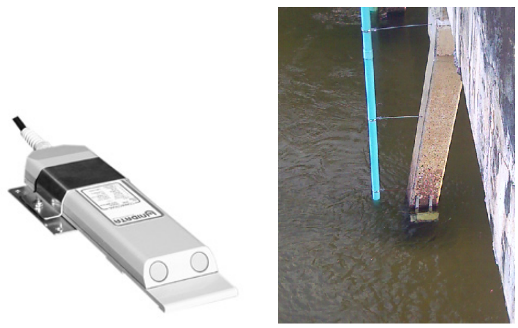

Figure 4. STARFLOW sensor and its installation.

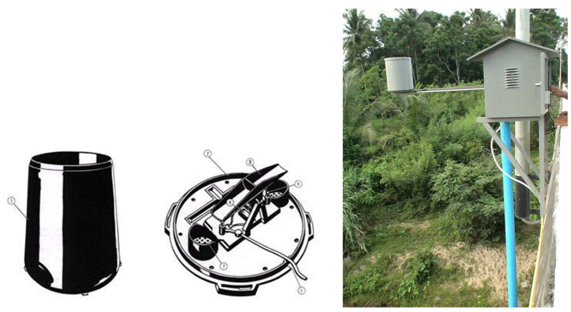

Figure 5. Precipitation sensor and its installation.

water near the bottom of an open channel, but not at the bed of the channel, to avoid accumulating debris. Its transducer sensor is horizontally and vertically aligned with the flow. For water depth measurement, STARFLOW uses a solid state pressure sensor mounted underneath. STARFLOW has a water depth measurement range of 0 to 5 meter. Its accuracy is ±0.25% of the workable range. This equipment runs on the power of 12 volts DC source. STARFLOW also has an additional ability to measure water velocity using Doppler shift where the frequency of the sound reflected from a moving target is varied by the velocity of the target, that is, STARFLOW uses the in-water particles moving in an open channel as its reflective targets in order to measure water velocity. The measurement range is 21mm/s to 4500mm/s bidirectional with resolution of 1mm/s and accuracy of 2%. In our measurement, we notice that STARFLOW is quite sensitive to water velocity fluctuations in the channel. As a result, continual velocity logging with a STARFLOW will show cycles of velocity fluctuation. In order to attenuate the effect of short period fluctuation cycles and obtain more accurate data, we use the average velocity over a time interval instead of raw measured data. With water velocity and cross sectional data of installed open channel, flow rate can be calculated. STARFLOW is connected to GDU via RS-232 and Serial Data Interface at 1200 baud (SUI-12) communications. When the water information is acquired through the sensor, it will be transmitted to the GDU for data processing and then data transmission via the mobile GPRS communication tunnel to the control center.

For the measurement of precipitation, we employ a precipitation sensor, which is a tipping bucket rain gauge system. The sensor uses a reed switch as a main component to detect the amount of rain from the tipping bucket. The orifice of this sensor is approximate 200 cm², complying the rules of the German Meteorological Service. The corresponding bucket content is 4 cm³, providing a resolution of 0.2 mm precipitation with the accuracy of ±2% for 0 to 25 mm/h and ±3% for 0 to 50 mm/h. The precipitation sensor is connected to a digital input terminal of a GDU. The GDU detects the on/off switching of the sensor reed switch to count the number of tipping buckets in order to calculate precipitation.

In Figure 6, we illustrate the wiring diagram of wireless monitoring sensor unit at a remote site. All equipment is well housed in a heavy-duty metal cabinet. We also installed two fans for ventilation in the cabinet in order to allow inside equipments to run under operational temperature. The GDU is able to detect whether the fans are running or it will notify system administrators via SMS. In addition, the GDU will inform if there is any intrusion by opening the cabinet door. We also found that the electricity sometimes is not available at some locations. An unexpected power disruption can cause equipment fatalities and service interruption. As a result, we employ an uninterruptible power supply (UPS) and surge protector to allow all the equipment to run at least twenty four hours with a continuous supply of electric power when utility power is not available. We also concern whether the UPS is able to withstand in a very humid environment. Therefore, a UPS with the conformal-coated boards of its power module is employed to avoid damage due to humidity.

3.3 Data transmission and processing

The goal of the flood monitoring system is to maintain members of a distance GDU group as nodes of a flood monitoring infrastructure so that services, such as reliable communication and real-time information access, can be implemented on top of this structure. The system was designed such that it provides reliable network management to allow smooth transmission of water-related data. The system has mechanisms that allow remote nodes to connect to the control center, and the system has procedures for managing the entire wireless network. For example, any GDUs can be

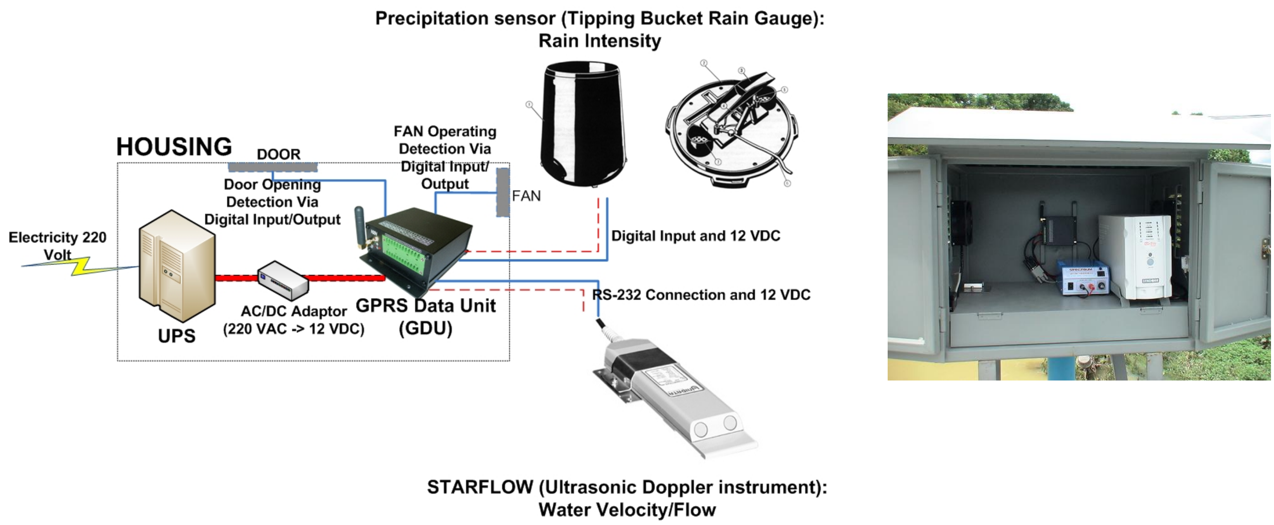

Figure 6. The Implementation Diagram of Wireless Sensor Unit and the installation.

configured online from the control center and the GDUs' firmware can be updated through the GPRS communication. In order to manage GDUs online from the control center, we implement GPRS Gateway software, which is developed based on the API Library provided by the manufacturer. The software is a tool based on the client/server system architecture and is interfaced with a relational-model database. The software architecture of the system is shown in Figure 7.

In Figure 7, the GPRS Gateway API is divided into four functions:

1) Data Command to send/receive data to/from GDUs.

2) Firmware upgrade to upgrade GDU's firmware online.

3) Box Control Command to remotely manage GDUs, e.g., reboot GDU, poll the interfaces of GDUs, obtain GDU logger, PING GDUs to verify whether the GDUs are still online, etc.

4) Box Configuration Command to configure GDUs online.

Those commands work in two modes: Non-Blocking I/O or Block I/O. There are two types of data retrieved from each GDU. The first one is the precipitation data from the precipitation sensor. For this type of data, the GPRS Gateway server counts the number of tipping buckets for a specific time interval so that the intensity of rain is obtained. The second type of data is retrieved from STARFLOW. The STARFLOW software compliments the operation of the STARFLOW instrument by providing a software that is used for loading, unloading and communicating with the device from the RS-232 connection. However, all STARFLOWs are not directly connected to the server at RS-232 port. The method we use to transport this type of data is that we implement a middleware that acts as a virtual RS-232 bridge overlay the GPRS tunnel. We employ a so-called VirtualCOM, which allows a server to communicate with remote devices connected to GDU as if there is a cable directly connected the server to the GDU. The data then go through GPRS tunnel instead of a real cable. The server can communicate with all STARFLOW sensors using VirtualCOM, in which the data will be forwarded through GPRS tunnel to the GDU, which will then send to the sensors through RS-232. The path of the data from the sensors to the server is vice versa. Figure 8 illustrates the logical structure of the implemented VirtualCOM. We also developed server management and database as parts of the GPRS Gateway server. The two main functionalities of this module is to 1) set the TCP/IP port for the server and manage concurrent TCP/IP connections between GDUs and the server and 2) retrieve all data obtained from GDUs and put into the system database.

3.4 Database and application server

The implementation and functionalities of the database and application server of the real-time flood monitoring system is discussed in this section. Figure 9 shows the homepage of the real-time flood monitoring system. The current version of the system is implemented using PHP and JAVA as the web application and MySQL as its relational database.

The real-time flood monitoring system is implemented by dividing into modules: real-time data reporting from sensors, forecasting, statistical and historical information module, and warning module. The system architecture is illustrated in Figure 10. The real-time reporting module collects the data from the database, which interfaces with

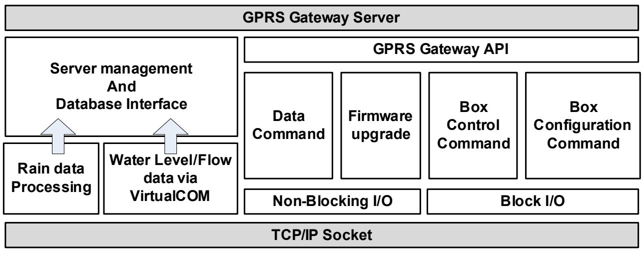

Figure 7. System architecture of GPRS Gateway Server.

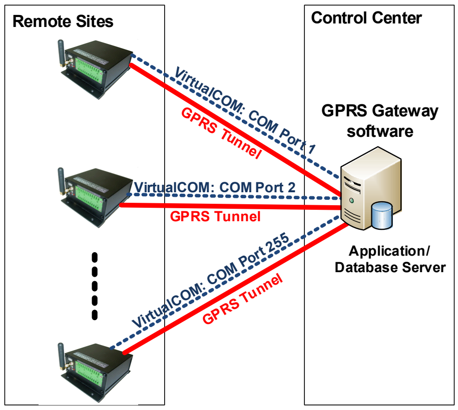

Figure 8. Logical structure of the implemented VirtualCOM.

Figure 9. Web-Based Real-time flood monitoring system.

the GPRS Gateway server, and displays it to users. An API-based application, which acts as a small agent on the server, pulls the most recent (latest record) measured data from the sensor at every 10 minutes interval. The system will then show the latest water information at every location to the user as illustrated in Figure 11.

The forecasting module can forecast the water condition including water leve l, flow, and precipitation level in the next 24 hours by employing neural network model built into the system. Neural network model used in this study is rather simple since the focus of this version of the system is on data collection and communication. The next phase of the development will be more focused on this part. By using water conditions as input, the ANN then predicts the water conditions in the next 24 hours. Together with the warning module, the system can alert the authorities if a certain criteria is met.

The historical data module uses the data in the database to show the water information in the past in the form of graphs and table as shown in Figure 12. The warning module uses the data output from the forecasting module as a criteria in informing the authority to issue a warning or perform some appropriate actions. The criteria in sending our a warning to local authorities can be configured from within the system i.e. at what water level the warning should be issued. The warning can be sent to the user in the form of SMS through GSM network or be sent to the user via FAX or e-mail.

Not only the application can be accessed from a web browser via http protocal. The WAP-based version of the system was also implemented in order for those who are on the move can access the same information as can be seen on web-based application. However, some graphical outputs may not be accessed from WAP. The information available to WAP user was made possible by having the WAP module

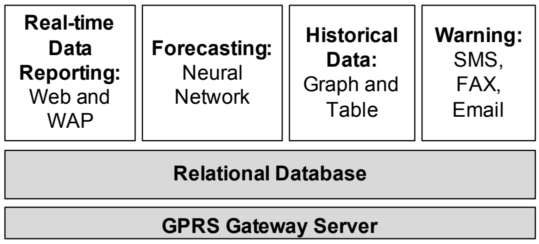

Figure 10. System architecture of the database and application server.

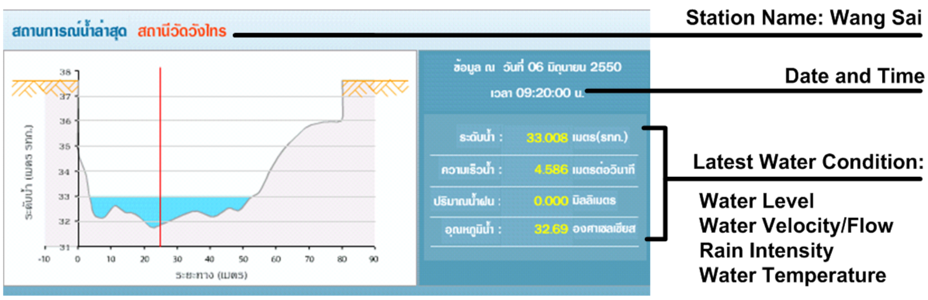

Figure 11. Latest Water Condition at Wang Sai station with the cross section of the open channel

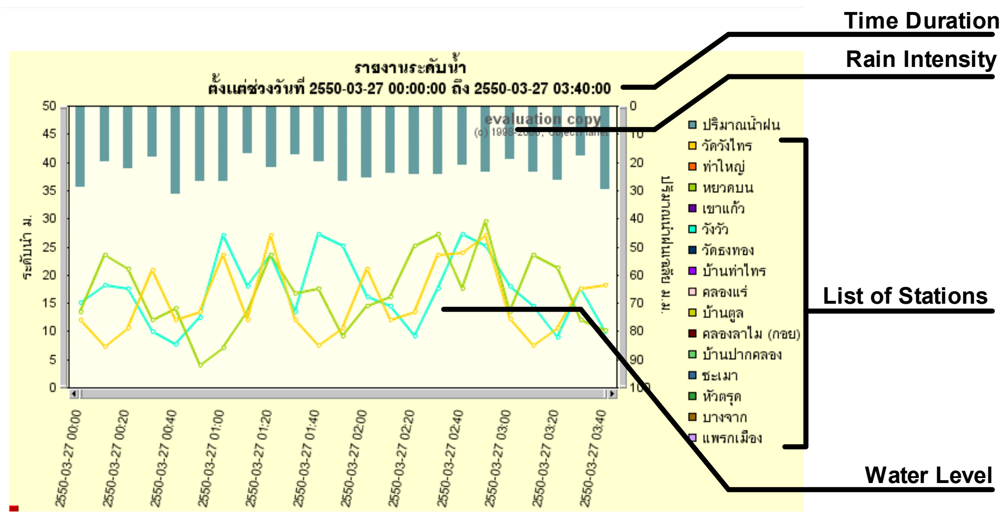

Figure 12. Historical View of Water Condition

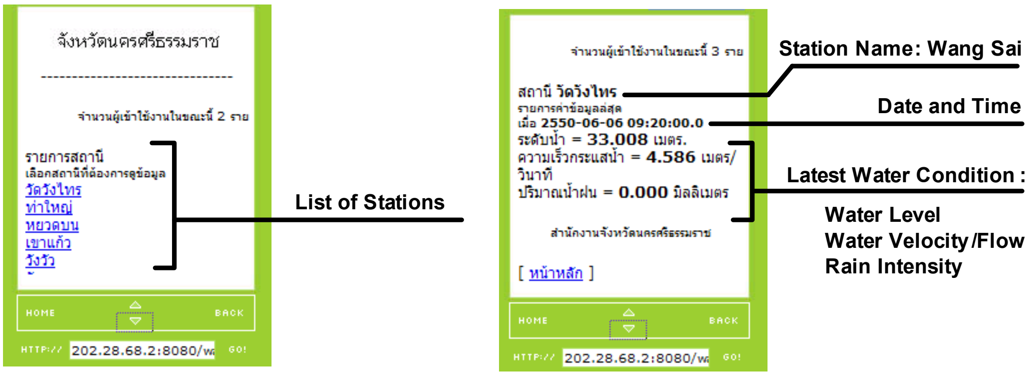

Figure 13. WAP-based real-time monitoring of water data.

implemented in this real-time monitoing system. The WAP interface is shown in Figure 13.

4. Summary and Conclusion

The main objective of this research work is to develop a real-time flood monitoring and warning system for a selected area of the southern part of Thailand. The system employs the use of advance sensing technology in performing real-time monitoring of water information. The developed system is composed of three major components: 1) sensor network, 2) processing and transmitting modules, and 3) database and application server. The GPRS sensor network is implemented at 15 remote sites, where network infrastructure is not available. The connectivity is done through the wireless GPRS tunnels. The sensor network measures water-related data while the processing and transmission module is used to transmit measured data to the database and application server. The database and application server is implemented as a web-based application to allow users to view real-time water-related data as well as historical data. The application server is also able to send warnings to the responsible authorities in case of emergency. We conclude with a brief discussion on some issues:

1. For realizing sustainable social development, this study has successfully demonstrated a regional flood monitoring system for final verification of flooding situations. Previously, there was no flood monitoring equipments installed in the area. Local authorities measure flood-related information using conventional hardware and report the information to local stakeholders via an assigned RF communication channel. Often the reports are too late and are not very useful for them in responding to flood events. The developed system has been in service since July 2007. Since then, the system provides up-to-date flood-related information at every ten minutes from all the 15 remote sites. Users (authorities, stakeholders, and experts) can now obtain information from web browser in the office or on their mobile phones. For standardization, water level data is measured in the unit of mean sea level. This allows local authorities to compare the system data with the one obtained from their conventional tools. In addition, experts can exploit this accumulated information to better understand the behavior of floods. Our system, therefore, allows a much greater degree of availability and continuity than those conventional approaches. In particular, our flood warning system allows the authority to know the development of floods and then provide more effective and timely measures for disaster relief.

2. In software development aspect, our key implementation is VirtualCOM, which is a set of computer software programs and data structures that behaves as a virtual bridge between an application server and remote sensors connected to a GPRS data unit (GDU). VirtualCOM is independent from the type of employed remote sensors and data-retrieving software at the server. This enables a greater degree of integration and flexibility. It means that our system can be reused for many hardwares and software sensors.

3. We learned from this research work that with today's technology, the use of sensor in sensing the information remotely, especially water information is possible and reliable. Although, there are numbers of sensors to choose from. In this work, we use STARFLOW from UNIDATA and GDU from NXN due to the facts that these sensors come with a very good management software for allowing one to manage them remotely. Moreover, these sensors come with an API that we can employ to customize their behaviors to suit our needs. It should be noted that implementing sensor network in a remote location can cause some difficulties if the GPRS in those area is unstable. The GPRS connection failure can cause difficulty in connecting the sensor at the remote site. However, with good sensor management software, remote sensors can be rebooted from the central office.

4. A technical problem appears in the mobile transmission at GDU stations. Since most GDUs are implemented in a remotely rural area, the cellular signal strength received at some remote stations is quite weak. With verification in the transmission, we found many weak signal reception errors. This problem causes high volume of retransmissions. In order to increase the effective range of our wireless network, we implement a customized patch antenna, a high

gain antenna, at each weak-signal-reception station. It operates in the frequency range of GSM-1800 system with the gain of about 5dBi. This antenna is specifically designed for fixed location, permanent mount applications, and waterproof. As a result, the GPRS connection becomes more stable.

The forecasting and early warning systems will continue to play a vital role in providing accurate and reliable warning information for the southern provinces of Thailand to enable them to better prepared for unnecessary damages and losses. Our flood monitoring system is adequate in terms of real-time data acquisitions. However, in order to enhance efficiency of flood prevention, the system could be integrated with modern space technologies and Geographical Information Systems (GIS). Today, space technologies are considered an efficient tool for risk assessment and emergency management systems. The integration of the system with these technologies will enable the system to determine the flood affected areas by exploiting the collected flood-related data and different image processing techniques such as data merging, segmentation and classification to enhance the authorities to make better decisions on managing flood.

Acknowledgements

The authors gratefully acknowledge the support of the province of Nakhon Si Thammarat through the governor funding. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the view of the province of Nakhon Si Thammarat. The authors has a very special thank to the system development team from the Center of Computer Services, Walailak University, for their hard work and efforts that have been put together to complete this vital system foundation.

References

Chang, N. and Guo Da-Hai. 2006. Urban Flash Flood Monitoring, Mapping and Forecasting via a Tailored Sensor Network System, Proceedings of the 2006 IEEE International Conference on Networking, Sensing and Control 2006, issue 23-25, pp. 757-761, April 2006.

Chang, Y., and Chang, N. 2002. The design of a web-based decision support system for the sustainable management of an urban river system, Water Science and Technology 46(6), 131-139.

Chen, S.P. 1990. Remote Sensing Analysis in Geoscience. Beijing Mapping Press, Beijing, China.

Creutin, J., Muste, M., Bradley, A., and Kim, S. 2003. River Gauging using PIV Techniques: A Proof of Concept on The Iowa River, Journal of Hydrology 277, 182-194.

Crossbow Technology 2007. http://www.xbow.com.

DeRoure, D. 2005. Improving Flood Warning times using Pervasive and Grid Computing, Quarterly of Royal Academy of Engineering, UK, 2005.

Hughes, D., Greenwood, P., Blair, G., Coulson, G., Pappenberger, F., Smith, P., and Beven, K. 2006. An Intelligent and Adaptable Grid-based Flood Monitoring and Warning System, Proceedings of UK eScience All Hands Meeting, 2006.

Hughes, D., Greenwood, P., Blair, G., Coulson, G., Pappenberger, F., Smith, P., and Beven, K. 2006. GridStix: Supporting Flood Prediction using Embedded Hardware and Next Generation Grid Middleware, Proceedings of the 2006 International Symposium on World of Wireless, Mobile and Multimedia Networks Table of Contents, pp. 621-626.

Louhisuo, M., Rauste, Y., Andersson, K., Häme, T., Ahola, J., and Morohoshi, T. 2004. Use of SAR data for natural disaster mitigation in the mobile environment, Proceedings of the 2004 Envisat and ERS Symposium, European Space Agency, (Special Publication) ESA, pp. 2013-2020, 2004.

Manusthiparom, C., and Apirumanekul, C. 2005. Flood Forecasting and River Monitoring System in the Mekong River Basin, Second Southeast Asia Water Forum, August 29th-September 3rd, 2005.

MeteoClima 2010. Precipitation Sensor. http://www.fischer-barometer.de/english/index.htm?niederschlag/nied menge.htm

NXN Technology 2010. GT-511 GPRS Data Transceiver, http ://www.nxn.com.tw/GT-511.php

OAS. 1990. Disaster, planning and development:managing natural hazards to reduce loss. Department of Regional Development and Environment, Organization of American States, Washington, DC, p. 80

Rodden, T., Greenhalgh, C., DeRoure, D., and Friday, A. 2005. Extending GT to Support Remote Medical Monitoring, Proceedings of UK e-Science All Hands Meeting, Nottingham, UK, September 2005.

Sapphaisal, C. 2007. Forecasting and warning flood, Civil Engineering Magazine, Engineering Institute of Thailand, Thailand, Vol. 2, pp.38-49.

UNIDATA. 2010. STARFLOW System, http://www.unidata.com.au/products/starflow/

UNDRO. 1991. Mitigrating natural disasters: phenomena, effects and options. United Nations Disaster Relief Coordinatior, United Nations, New York, p. 164.

Veijonen, T., Louhisuo, M., Ahola, J., and Timonen, M. 2006. ENVIMON disaster monitoring system, International Disaster Reduction Conference, September 2006.

Zhang, J., Zhou, C., Xu, K., and Watanabe, M. 2002. Flood Disaster monitoring and evaluation in China, Envionmental Hazards, Vol. 4, 2002 p.33-43.