Total Water Management System

by

Goay Xuan Hui

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Technology (Hons)

(Business Information Systems)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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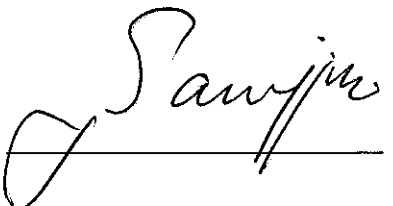
Approved by,



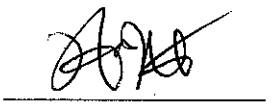
(MR. LOW TANG JUNG)

Low Tang Jung
Senior Lecturer
Computer & Information Sciences
Universiti Teknologi PETRONAS
31750 Tronoh
Perak Darul Ridzuan, MALAYSIA.

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



GOAY XUAN HUI

ABSTRACT

The purpose of this pilot project is to embark on a total water management system (TWMS) that enables the efficient and effective management of water by addressing both quantity and quality aspects through real time water quality monitoring, water usage monitoring and water leakage monitoring in water distribution network.

TWMS is a previous project embarked on by Universiti Teknologi PERONAS (UTP) research community, which is a wireless sensor network (WSN) testbed set up in one of the research laboratories in UTP.

In this project, the major work shall focus on implementing a wireless solution in UTP students' villages, to provide a WSN data collection for monitoring and analysis purposes hence the objective is to find an optimal water management solution.

The targeted monitoring and control setup would be the wash rooms located at the selected levels and selected houses of each male and female village. Wireless sensors that are installed on the strategic water pipes will be used to measure the water usage, water leakage, and water quality. All data collected would be transmitted automatically to a lab server for storage, archive, and analysis. Command and control signaling can be transmitted wirelessly to control the possible leakages.

The outcome of this project shall provide vital statistics and information on the managing and control of water losses, which ultimately may contribute to the improvement of the sustainability of clean water supply and distribution. Moreover this project might provide a platform for wireless sensor technology to become a strategic enabler for a total water management system.

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INTRODUCTION

1.1 Background of Study

Wireless sensor network (WSN), a network that combines sensors, central processing unit and radio, has been generally used in environmental data collection, security monitoring (transferring of report when there is security violation) and sensor node tracking (tracking of tagged object) [1].

Many studies have been done to investigate the implementation of various sensing technologies in WSN, especially in terms of environmental data collection, as a start of water resources management tool.

This paper will focus on using WSN as an integrated water resources management tool to manage water more efficiently and effectively by addressing both quantity and quality aspects through the real time monitoring of water usage, water leakage and water quality in water distribution network.

1.2 Problem Statement

Postel [2] quoted that "Water is the basis of life and the blue arteries of the earth! Everything in the non-marine environment depends on freshwater to survive". Water is, undeniable, a very precious element to every living creatures in this world, and yet, there are four major water-related problems, which are water shortages, water pollution, flood and landslide [3]. This study will focus on water shortages and water pollution as these are the problems that affect human daily life.

Among all the available water sources in this world, only 2.53% out of it is fresh water, which some two thirds of this is even being locked up in glaciers and permanent snow cover [4].

The availability of freshwater is further reduced by the following factors:

- Pollution

  As [4] reported, out of the disposed waste, some 2 million tons of it are disposed receiving waters, which include industrial wastes and chemicals, human waste and agricultural wastes. 1 litre of this wastewater is assumed to be able to pollute 8 litres of freshwater, with the possible present pollution coverage of up to 12, 000km3 worldwide.

- Increasing population

  Statistic from [4] also indicated that the growing population of about 8 million people per year will increase the demand of water about 64 billion cubic metres per year. And, this increasing in population is accompanied by a better lifestyle for everyone, which adds to the rising in the percentage of per capita use in water.

- Climate change

  Some countries like North and Southern Africa, Middle East and parts of South East Asia and South America, have suffered from water scarcity due to low annual rainfall.

  All of these factors would one day lead to water scarcity that involves about 7 billion people in sixty countries at worst, and at best 2 billion people in forty-eight countries [4].

- Pollution

  Pollution is now everywhere as the result of rapid development of countries. This brings disruption to water supply services, human health, aquatic lives and also habitat. According to [4], water related diseases are the common causes of the illness and death suffered by the poor in developing countries, which the estimate death rate in 2000 was 2,213,000.

It is estimated that in developing countries, about 3 million people will die at a younger age every year, due to water related diseases. Among these, infants and young children stand the largest percentage, followed by women [4].

In the context of Malaysia, water resource management programme is mainly targeted on river basin to monitor the quality of water resource. This study will then contribute to a total water management system that enables the efficient and effective management of water by addressing both quantity and quality aspects through real time water quality monitoring, water usage monitoring and water leakage monitoring in water distribution network.

Furthermore, real time detection of water leakages and water usage using smart water meter is now emerging as a commercial product where the market demand is soaring. By 2016, worldwide installation of smart water meters is estimated to increase from 8.0 million in 2010 to 31.8 million [5]. Last but not least, it ensures that people would have access to safe drinking water accordance to the standards set by the government.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The main objective of the study is to create a web-based application that utilizes the wireless sensor network (WSN) to monitor water resource usage, water quality, detect leakages and remotely switching on/off the valves.

The system hence allows personnel who maintain or control the water resource to perform his/her tasks more efficiently regardless of time and place. Web-based application allows the personnel to access the water resource data anytime, anywhere as long as there is internet connection.

With wireless sensors transmitting water resource data to the server wirelessly, monitoring and maintenance become much more efficient as personnel need not be on site to gather water resource information and react after that. Water resource information is received on real time and available for analysis on the spot, hence speeding up the time for actions to be taken.

1.3.2 Scope of Study

The major study to be done includes the existing wireless technologies that are capable of performing the task for the Total Water Management System. Besides, the water quality standard measurements and parameters are studied to gain understanding in the suggested levels for the system development.

CHAPTER 2
LITERATURE REVIEW

2.1 Water Leakage Monitoring

As indicated in [6], non-revenue water (NRW) is the difference between the volumes of water that is being pumped into the distribution system with the volumes of water that is actually being billed to the customers, which is due to:

- Physical or real losses which are the losses caused by leakages in distribution system
- Commercial losses which are the losses caused by mistakes in customers' metering
- Unbilled authorized consumption which means the usage of water by the authorities for operational purposes

In comparison, NRW is defined as "a significant amount of treated water that does not generate any revenues" in the work of [7]. According to [8], the volume of NRW in Malaysia in 2009 could fill up 720, 000 Olympic-size swimming pools, which costs about RM1.64 billion, revealed by the Association of Water and Energy Research Malaysia (AWER), who has set the target of keeping the national NRW below 20 percent by 2020, compared to the 36.93 percent in 2009. It is also stated in the statement that the estimated levels of NRW in 2010 among the cities in Malaysia are ranging from 18% (in Penang) to 55% (in Pahang), which are far away higher than the average NRW level in major Asian cities shown below.

Non-Revenue Water (NRW) achievements by major Asian cities

No.	City	NRW recorded (%)	Year of record
1	Beijing, China	12.5	2008
2	Guangzhou, China	14.8	2007
3	Mumbai, India	13.6	2005
4	Osaka, Japan	6.9	2007
5	Seoul, South Korea	7.0	2009
6	Singapore	4.6	2009
7	Tokyo, Japan	3.1	2008

Source: Asian Green City Index, Siemens, 2011 — SoonJoonWai / Malaysiakini

Figure 1: NRW Level in Major Asian Cities

There are several reasons that contribute to the high level of NRW in the country [9]:

- The aging of piping infrastructure, which 40% of the pipe network is constructed since 40 to 60 years ago and longer
- Poor maintenance of piping network, due to the lack in funding for asset replacement and also poor construction
- Illegal connections which largely contributes to commercial losses
- Nonexistence of a sound implementation for Active Leakage Control

A shown in the figure below, physical losses make the largest contribution to the total water losses. This is further supported by [10], reporting that "by cutting physical losses to half the present level (which is technically feasible), 150 million people could be supplied with already-treated water."

Region[a]	Urban Population with Service Connections (in millions)	System Input Volume		Non-Revenue Water		Physical Losses[b]	Commercial Losses	NRW	Value[c]
		l/c/d	m³/d	%	(m³/d)	(billion m³/year)			billion $/year
Central and West Asia	29	450	13,050,000	40	5,220,000	1.4	0.5	1.9	0.6
East Asia[d]	605	230	139,150,000	25	34,787,500	9.5	3.2	12.7	3.8
Middle East[e]	167	250	41,750,000	30	12,525,000	3.4	1.1	4.5	1.4
South Asia[f]	202	180	36,360,000	35	12,726,000	3.5	1.2	4.7	1.4
Southeast Asia	133	280	37,240,000	35	13,034,000	3.6	1.3	4.9	1.5
Total Asia	**1,136**		**267,550,000**		**78,292,500**	**21.4**	**7.3**	**28.7**	**8.6**

[a] Regions are slightly different from ADB's regions.
[b] A 75%/25% split was assumed.
[c] Water was valued with $0.3/m³.
[d] Including Japan.
[e] Excluding Egypt
[f] Including Pakistan.

Source: Urban Population: WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation 2006 data. NRW estimates: Roland Berger.

Figure 2: NRW Estimates and Values in Asia

With these findings, the study will focus on detecting water leakages in real time and thus remotely on or off the valves.

2.2 Smart Water Metering Technology

Smart meter is defined as "an electric meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes" [11]. In the work of [12], smart water metering is known as "water meter equipped with radios that deliver hourly consumption data via a fixed network system".

According to [13], there are two types of smart meter available:

- Automated Meter Reading (AMR) that enables one way communication from the meter to the central system
- Advanced Metering Infrastructure (AMI) that enables two way communications from the meter to the central system, as well as from the central system to the meter

These types of smart water meters allow the transformation of data to information (for AMR), where analysis on data can be done to produce information that is much more meaningful; while AMI allows the transformation of information to knowledge where actions can be performed based on the information gathered.
In this study, the implementation of AMI will enable the:

- Tracking of water usage in real time
- Analysis on water consumption data to be done
- Identification for leakages and thus remotely turn on or off the valves

In comparison to the work shown in [14], traditional water meter only functioning as a water usage measurement device, where the data is static, which means the data would not be able to lead this study anywhere further.

Figure 3: Typical Residential Water Meter [14]

Figure 4: Smart Meter Used in Europe [11]

2.3 Water Quality Monitoring

So far, Malaysia has only embarked on water quality monitoring in river basin through two types of monitoring:

- Manual water quality monitoring (MWQM)
- Continuous water quality monitoring (CWQM)

In CWQM where the quality of water is monitored in real time, data is collected every 15 minutes [15].

In this study, water quality monitoring will be embarked on the water distribution network, where the variables are the parameters that have been mandated by the Malaysia government to be monitored at least once a week against the National Drinking Water Quality Standards (NDWQS) [16].

There are six parameters that require the monitoring of at least once per week. However, due to the limitation in terms of money resources, the study will focus on only three parameters that are more feasible to be monitored through online monitoring equipments that are colour, pH and residual chlorine (highlighted in red). The data that will be transmitted in real time to the analysis lab will be used to compare against the standards set in NDWQS.

Parameters	Recommended Standards	Mandatory Standard
Coliform Organism		
E. Coli		
Turbidity		
Colour (TCU)	5	15
pH	7.0 – 8.5	6.5 – 8.5
Residual Chlorine (mg/l)	-	0.1

Table 1: NDWQS [16]

According to [17], it is important for the parameters above (highlighted in red) to stay within the limits set as:

Colour

Colour informs what processes have occurred within the water. Dark brown translucent waters contain organic matter that prevents microbes from being disinfected. Light brown or reddish opaque water contain mineral particles that demand further physical filtering.

pH

pH needs to be taken into consideration during the quality monitoring process as it has large impacts on the effectiveness of drinking water filtration in removing turbidity.

Residual Chlorine

Although it does not have direct health impacts, the upper limit set would ensure acceptable taste levels of the drinking water.

2.4 Wireless Technology

2.4.1 Bluetooth

The Bluetooth technology is one of the considerations for the implementation of Total Water Management System project. The Bluetooth technology is a specification that attempts to provide a standard method of wireless communication between various personal devices, with a complete software framework and its own protocol. [19][22]

The development of the technology is supported by the Bluetooth SIG (Special Interest Group) and envisioned to replace cables in connecting portable and/or fixed devices with its short-range communication technology. The Bluetooth technology is designed to be low cost, low power radio frequency (RF) technology that works over the unlicensed 2.4GHz ISM band.

The transmission range of Bluetooth is divided in 3 classes, which are characterized by their output power:

- Class 3: up to 1 meter or 3 feet; 1 milliwatts
- Class 2: 10 meters or 30 feet, most commonly found and used; 2.5 milliwatts
- Class 1: 100 meters or 300 feet, used primarily in industrial use cases; 100 milliwatts

The Bluetooth technology employs frequency hopping spread spectrum (FHSS) to communicate in a master and slave module. A group of Bluetooth devices which are going to communicate with each other can be a master or slave individually, depending on the situation. In order to have all devices successfully communicating with each other, they must have a synchronized hopping sequence.

The device which provides the synchronization reference will act as the master for the group and all other devices will be the slaves following the hopping sequence provided by the master. With these connections made, a piconet is formed. In a piconet, only the slaves communicate only to the master. A piconet can have up to seven active slaves managed by one master. [20][21]

When one slave in a piconet communicates with a master of another piconet, a scatternet will be formed. This can be done on a time-division multiplex basis. Besides, a master of a piconet can be a slave in another piconet. We should note that hopping sequences of different piconets are not synchronized, and each piconet has its own hopping sequence. [20][21]

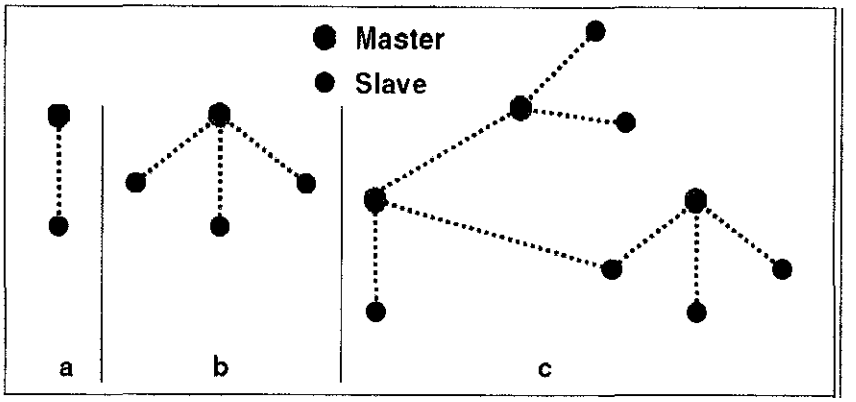

Figure 5: Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet operation(c). [20]

Bluetooth uses Gaussian frequency shift keying (GFSK) to modulate the data to frequencies around 2.4 GHz. The frequency spectrum is divided up into 79 channels spaced 1 MHz apart. Data is transmitted at 1 Mbps. For security benefits and noise reduction, a Bluetooth transmitter employs frequency hopping, switching channels up to 1600 times a second. Bluetooth can support an asymmetric link with up to 723.2 kb/s in one direction and 57.6 kb/s in the return direction, or a symmetric link with 433.9 kb/s in both directions at once. [23]

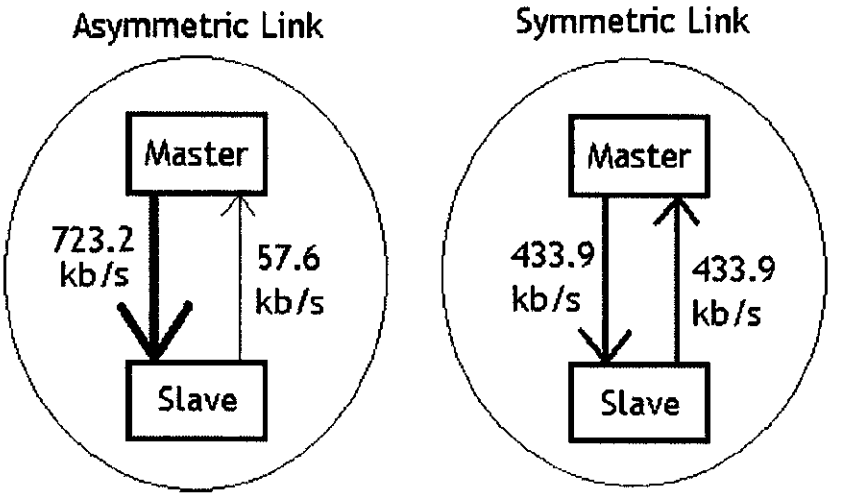

Figure 6: Asymmetric & Symmetric Link in Bluetooth. [23]

Generally, the Bluetooth technology is an advantage that it is cableless, inexpensive, easy to set up and use, and device compatibility.

Currently, Bluetooth technology is used in various devices such as headset, headphones, car adapter, printers and data transmission in mobile phones.

2.4.2 ZigBee

The ZigBee technology is another wireless technology considered to be implemented in the Total Water Management System project. It is a wireless networking protocol targeted towards automation and remote control applications and sensor networks. [24][25]

The development of ZigBee technology is initiated by the ZigBee Alliance and later joining forces with the IEEE 802.15.4 Committee. IEEE and ZigBee Alliance have been working closely to specify the entire protocol stack. IEEE 802.15.4 focuses on the specification of the lower two layers of the protocol (physical and data link layer), while ZigBee Alliance aims to provide upper layers of the protocol stack (from network to the application layer) for interoperable data networking, security services and wireless home and building control solutions. [8] The technology is designed to provide low cost and low power connectivity for devices that need long battery life but do not need high data transfer rates. In other words, ZigBee intends to capture market of devices that do not need high data transfer rates as in Bluetooth.

The ZigBee compliant wireless devices are expected to transmit data in a range of 10 to 75 meters. It is operating in the three unlicensed bands worldwide with different data rates:

- 2.4GHz for global
- 915MHz for Americas
- 868MHz for Europe

The maximum data rate for these frequency bands are fixed as:

- 250 kbps for 2.4GHz
- 40 kbps for 915MHz
- 20 kbps for 868MHz

A ZigBee system consists of several components which the most basic is the device. A device can be a full-functioned device or a reduced-function device. A reduced-functioned device is meant for extremely simple applications that do not

transmit large amount of data. A ZigBee network shall include at least one full-functioned device, acting as the Personal Area Network (PAN) coordinator. Note that a full-functioned device can communicate with either full-functioned device or reduced-functioned device; while a reduced-functioned device can only communicate with a full-functioned device. [24] ZigBee's network generally supports 3 types of topology: star, peer-to-peer and cluster tree.

2.4.3 Star Topology

In the star topology, the communication is established between devices and a single central controller, called the Personal Area Network (PAN) coordinator. The PAN coordinator can be powered by the mains while the devices are most likely powered by battery. Applications that benefit from this topology include home automation, personal computer (PC) peripherals, toys and games. After a fully functioned device is activated for the first time, it establishes its own network and become the PAN coordinator. Each starting network chooses a PAN identifier, which is not currently used by any other network within the radio sphere of influence. This allows each star network to operate independently. [24][26]

The figure below shows the model of a star topology:

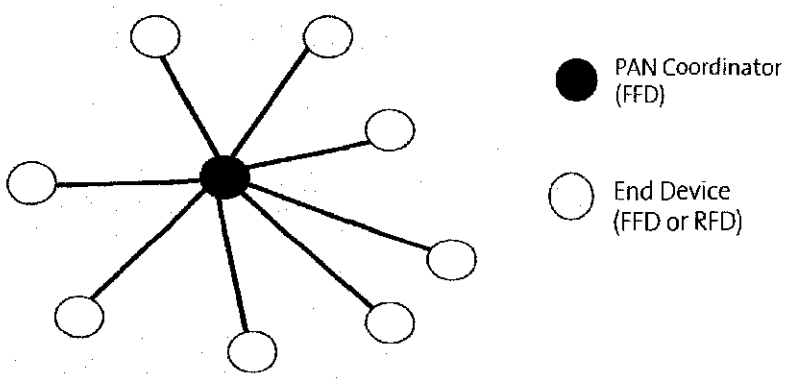

Figure 7: Star Topology

2.4.4 Peer-to-peer

In the peer-to-peer topology, there is also one PAN coordinator. But, it is different than the star topology that any device that is in range to each other can communicate with one another. Network of this topology can be ad hoc, self-organizing and self-healing. Applications such as industrial control and monitoring, wireless sensor networks, asset and inventory tracking would benefit

from such a topology. It also allows multiple hops to route messages from any device to any other device in the network. It can provide reliability by multipath routing. [24][26]

The figure below shows a peer-to-peer topology:

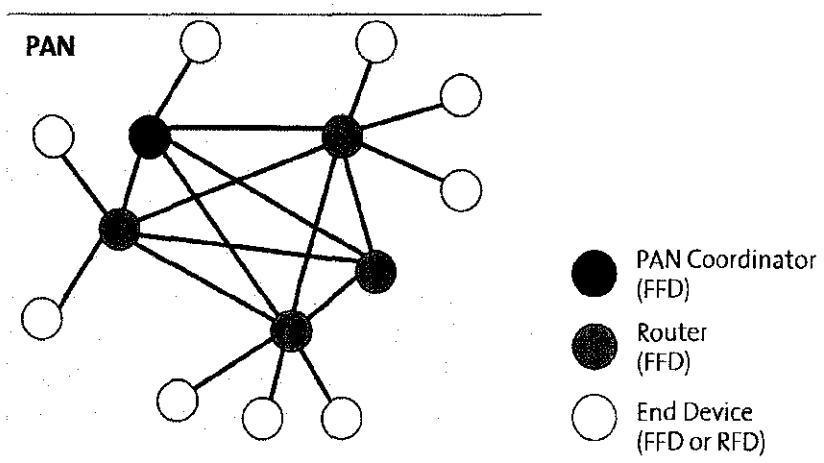

Figure 8: Peer-to-peer Topology

2.4.5 Cluster Tree Topology

Cluster-tree network is a special case of a peer-to-peer network where most devices are full-functioned devices and a reduced-functioned device may connect to a cluster-tree network as a leave node at the end of a branch. Any of the full-functioned devices in the topology can act as a coordinator to provide synchronization services to others but only one of these coordinators however is the PAN coordinator.

The PAN coordinator forms the first cluster by establishing itself as the cluster head with a cluster identifier of zero, choosing an unused PAN identifier, and broadcasting beacon frames to neighboring devices. A candidate device receiving a beacon frame may request to join the network at the cluster head. If the PAN coordinator permits the device to join, it will add this new device as a child device in its neighbor list. The newly joined device will add the cluster head as its parent in its neighbor list and begin transmitting periodic beacons such that other candidate devices may then join the network at that device. Once application or network requirements are met, the PAN coordinator may instruct a device to become the cluster head of a new cluster adjacent to the first one.

The advantage of this clustered structure is the increased coverage area at the cost of increased message latency. [24][26]

The figure below shows a cluster tree topology:

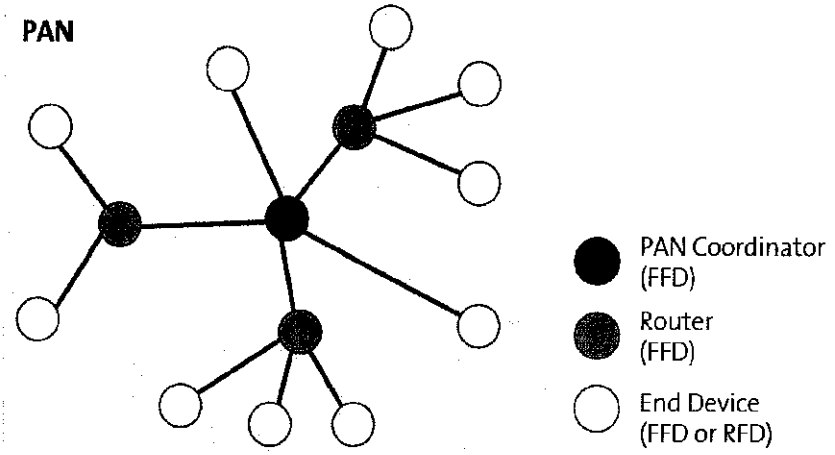

Figure 9: Cluster Tree Topology

The physical layer (PHY) of ZigBee follows the standard of IEEE 802.14.4 PHY standard, which offers two PHY options based on frequency band. Both options are based on direct sequence spread spectrum (DSSS). The data rate is 250kbps at 2.4GHz, 40kbps at 915MHz and 20kbps at 868MHz. The higher data rate at 2.4GHz is attributed to a higher order modulation scheme. Lower frequency provides longer range due to lower propagation losses. Low rate can be translated into better sensitivity and larger coverage area. Higher rate means higher throughput, lower latency or lower duty cycle.

Table below summarizes the information:

PHY (MHz)	Frequency Band (MHz)	Spreading Parameters		Data Parameters		
		Chiprate (kchip/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
868 / 915	868 – 868.6	300	BPSK	20	20	Binary
	902 – 928	600	BPSK	40	40	Binary
2450	2400 – 2484.5	2000	O-QPSK	250	62.5	16-nary Orthogonal

Table 2: Frequency bands and data rate

Generally, ZigBee is a wireless technology that provides low cost and low power connectivity that is focusing on controlling and monitoring applications. It is designed to cater applications that do not need high data rate as compare to Bluetooth.

Currently, the ZigBee technology is used in applications such as light controls (light sensors / dimmers), heating control, air-condition control, remote control for consumer electronics, building automation (security, fire and safety systems) and more.

2.4.6 Z-Wave

Another wireless technology that was being considered for the Total Water Management System project is the Z-Wave. The Z-Wave is a low bandwidth half duplex oriented to the residential control and automation for reliable low cost wireless communications. [27][29]

The Z-Wave is first developed by Zensys, a provider of wireless networking technology for control and status reading applications, and currently being guided under the consortium of Z-Wave Alliance. The Z-Wave is not designed for large amount data transferring or data streaming or any timing critical data transfer. Its initial intention of creation was to provide a simple yet reliable wireless light and appliances control. Z-Wave operates at 908MHz in U.S. and 860MHz in Europe in the unlicensed ISM bands using frequency-shift keying radio. It has a data rate of 40kpbs and is general similar to the ZigBee protocol. [27][28]

Similar Bluetooth and ZigBee, Z-Wave is also applying the master and slave model for it connections. The Z-Wave system is appeared as a mesh network with a controlling device as the master and others are slave nodes. Controlling devices are the nodes in a network that initiate control commands and sends out the commands to other nodes, and slave nodes are the nodes that reply on and execute the commands. Functionality of a controller varies depending on the time it enters a Z-Wave network. If a controller is used to create a new Z-Wave network, it automatically becomes the primary controller, which is the "master"

controller. Only primary controllers have the capability to include/exclude nodes in the network, and not other controller nodes. A slave in the Z-Wave system has minimum or none knowledge on network topology. They are only capable of receives commands and performs an action based on the command. Slave nodes are unable to send routed messages to other slaves or controllers unless they are requested to do so in a command. [29]

A Z-Wave network may include up to 232 nodes, with the average communication distance of 100 meters between two nodes. The messages being sent are capable of hoping up to four nodes resulting the broader coverage of the network. Management of Z-Wave nodes constitutes of two main operations, inclusion/exclusion and association. Inclusion is the operation of initiating a new node in the network while exclusion is the operation of removing a node from the network by primary controller as mentioned earlier. The association operation is the creation of logical connections between devices. [29]

Generally, Z-Wave is a low cost, low bandwidth and low data rate wireless protocol that duplex oriented to the residential control and automation. The protocol is currently used widely in wireless lighting control such as light dimmer and other home appliances such as remote controls.

2.4.7 Wi-Fi

The Wi-Fi technology, a very common protocol nowadays, is another technology being considered in the Total Water Management System project. The technology is commonly used in Local Area Networks (LAN) for devices such as laptops, desktops or printers in order to provide mobility to network access in organizations or within a building.

The existence of Wi-Fi is initiated by the decision of United States' telecoms regulator, Federal Communications Commission (FCC) made in 1985 to open several bands of wireless spectrum to be used without government license. [30] The current Wi-Fi standards are the efforts of IEEE 802.11 committee that continuously working on the supplements and enhancements to the standard.

The Wi-Fi is a high data rate technology working in the unlicensed ISM bands of 2.4GHz and 5.2GHz.

Currently, Wi-Fi technology has four generations which are developed under different task groups under the IEEE 802.11 committee. Below is some basic information of the generations [31]:

Wi-Fi Technology	Frequency Band	Bandwidth or maximum data rate
802.11a	5.2 GHz	54 Mbps
802.11b	2.4 GHz	11 Mbps
802.11g	2.4 GHz	54 Mbps
802.11n	2.4 GHz, 5.2 GHz, 2.4 or 5.2 GHz (selectable), or 2.4 and 5.2 GHz (concurrent)	450 Mbps

Table 3: Wi-Fi Technology Generations

The spread spectrum techniques for radio transmission used by Wi-Fi are [32]:

- Direct Sequence Spread Spectrum (DSSS) which spreads the signal's power across a wider bandwidth by spreading the carrier that differs from other methods that rapidly move the carrier around. It does this by directly modulating the carrier with a high-speed code sequence which has the characteristics of pseudo-random noise (PN). The faster a carrier is modulated, the wider its bandwidth becomes.
- Orthogonal Frequency Division Multiplexing (OFDM) which utilized multiple carriers. Technically, the OFDM is not a spread spectrum technique because the subcarriers remain stationary and are not spread. However, it serves the same purpose of spreading signal power over a large band. It does this by breaking the signal into parts and transmitting each of the parts on a different subcarrier at a different center frequency. Thus a fast transmission is sent as many slow transmissions, simultaneously, on many different frequencies.

Each component of a WLAN requires a radio transceiver and antenna. Components are either stations or access points. Stations (STAs) are wireless LAN client radios. They can be incorporated into a LAN card installed in a desktop, a USB adapter, a PCMCIA or PC card, or can be integrated into the notebook or handheld device itself. Access Points (APs) form a bridge between wireless and wired LANs.

A Basic Service Set (BSS) is formed when two or more stations have recognized each other and established a network. The network can be configured in two basic ways [32]:

- Peer-to-peer (ad hoc mode) – This configuration is identical to its wired counterpart, except without the wires. Two or more STAs can talk to each other without an AP. When two or more stations form an ad hoc network, this is referred to as an Independent Basic Service Set (IBSS).
- Client/Server (infrastructure networking) – This configuration consists of multiple stations connected to an AP, which acts as a bridge to a wired network. A BSS in this configuration is referred to as being in infrastructure mode.

An Extended Service Set (ESS) is formed when multiple overlapping BSSs (each containing an AP) are connected together by means of a distribution system, usually a wired Ethernet LAN. BSSs whose ranges overlap must transmit on different channels to avoid interference.

Range between STAs and APs is up to 100 m (depending on data rate), but the overall range of an ESS is limited only by the range of the wired distribution system. Also, ESSs can be further extended with wireless links up to several miles by the use of directional range extender antennas. [32]

2.4.8 Wavenis

Wavenis is another technology that is being considered too. Wavenis is a two-way wireless connectivity platform, created in year 2000 by Coronis Systems. The technology is designed for use by applications that need to manage small amounts of data with low radio traffic and ultra-low-power management. [33]

Wavenis will support a wide variety of proprietary and standard application protocols, with both fixed and mobile monitoring capabilities because it is only a wireless connectivity platform. Wavenis does not compete with traditional technologies but rather comes as a complementary solution that adds an unlimited set of new usage scenarios. Thus, Wavenis allows its adopters to innovate in their markets with wireless devices that are not only cost-effective, but also run on a single set of batteries for many years depending on usage scenario. [33]

This ultra-low-power wireless technology operates in the global unlicensed ISM frequency bands of 433MHz, 868MHz and 915MHz. Wavenis applies the Frequency-hopping Spread Spectrum method for its radio transmission, giving it a programmable data rate of 4.8kbps to 100kbps. The typical data rate for the Wavenis technology is 19.2kbps. An advantage of the technology would be its transmission range which is up to 200m indoor and 1km LOS. [34]

Wavenis-enabled devices with both long- and short-range capabilities are already deployed in home comfort, building and industrial automation, smart metering, alarms and security, access control, medical and other UHF-active long-range RFID applications. [33]

2.4.9 Summary

After considering the various wireless technologies available, Wavenis is chosen for the Total Water Management System project. One of the reasons is that Wavenis has much longer transmission distance compare to other technologies. Bluetooth is certainly unsuitable due to its short range transmission as the data collector will be located in the Post-graduate lab at Building 1, a distance of at least 100 meters from the wireless sensors.

The second advantage of Wavenis is its ultra-low-power consumption and highly sensitive sensing feature. Although technologies like ZigBee and Z-Wave are also low power consumptions, Wavenis's battery set is able to work up to 15 years depending of usage scenario. Wi-Fi is not suitable in this sense as it needs main powered.

Besides, Wavenis is a wireless technology that is designed for automation, control sensing and smart metering which suits the function of the Total Water Management System project. Bluetooth and Wi-Fi in this case are unsuitable as they are not designed for these functions. ZigBee and Z-Wave might be suitable for these functions, but combining its other features such as range, power consumption, data rate, etc., they are not serving as good as Wavenis.

Hence, Wavenis is a better choice and it is chosen for the project. Below is a table summarizing the features comparison of the wireless technologies mentioned above:

	Bluetooth	ZigBee	Z-wave	WiFi	Wavenis
Frequency band	2.4 GHz	2.4 GHz/ 5.2 GHz	868MHz 915MHz	2.4 GHz/ 5.2 GHz	433/868/915MHz 2,4GHz
Data rate	1 Mbps	250 kcps	few kbps	5.5/11MHz	4,8 / 19,2 typ / 100kbps
PHY	FHSS / GFSK	DSSS	Mono-channel / FSK	DSSS/ OFDM	FHSS / GFSK
Reliability	+++	+++	-	+	+++
Low Power	+	++	++	-	+++
Long Range	-	-	+	+	+++
Low Cost	+	++	++	-	+++
Indoor Range	- (10m)	- (20m)	+ (50m)	+ (50m)	+++ (up to 200m)
Mesh network	-	++	-	-	+++
Standard protocol	+++	+++	-	+++	++ (designed with Bluetooth extension capabilities
Availability	+++	-	+++	+++	+++
Deployment	+++	-	+	+++	++

Table 4: Comparison of Wireless Technologies

CHAPTER 3
METHODOLOGY

The Total Water Management System (TWMS) is project that is implementation-based and requires data collections. The main research methodology for the project will be the installation of AMR and wireless sensors in the test bed which includes the bathroom unit of the male residential village block and also the female residential village block. The project contains three phases, which are:

- Pre-installation of AMR and wireless sensors
- Installation of AMR and wireless sensors
- Post-installation of AMR and wireless sensors

In different phases of the project, different activities are carried out to complete the project based on particular situations.

Besides, a web-based application named Total Water Management System will be developed to achieve the objectives of water resource monitoring and control on usage, quality and leakage.

3.1 Pre-installation of AMR and Wireless Sensors

Before the installation of AMR and wireless sensors, the project is mostly on paper where works done by others about the project are reviewed. The test bed for the project is identified during this stage and findings on elements to be monitored are searched in the literature review.

Next, to have a view and a concept of how the TWMS works a virtual environment is stimulated for further understanding and viewing. The stimulation is done using LabView 6.0 that is acquired from the E&E laboratory. Below are some screens from the LabView 6.0 software showing the TWMS in a simple form.

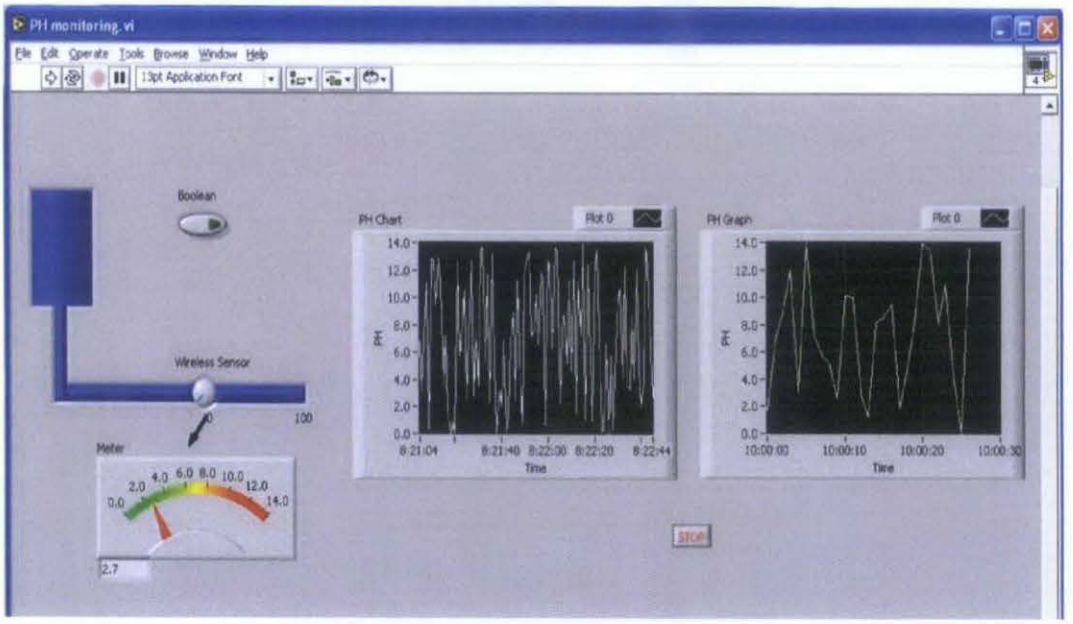

Figure 10: Front end view of the TWMS stimulation

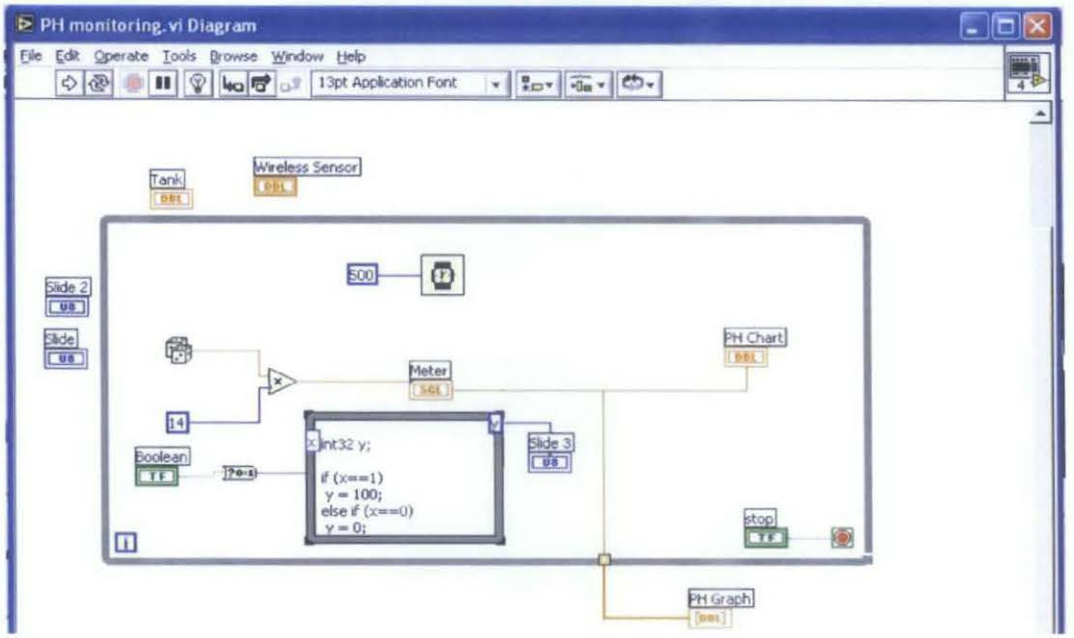

Figure 11: Back end view of the TWMS stimulation

The figures above show the layout of the systems. The stimulation in LabView 6.0 stimulates the sensor installed in the pipes collecting data and transmits them to the servers for storage, analysis and display. Besides, a valve control is stimulated the act as a on or off for the water pipe that could be control remotely.

The stimulation done will act as a reference on how the system operates after its real implementation.

3.2 Installation of AMR and Wireless Sensors

In the second phase of the project, the AMRs and wireless sensors will be installed into test bed, which are bathroom units in UTP male and female residential village blocks. The installation will be done by the equipment vendors following the architecture below:

- Wireless sensors installed at the water inlets such as taps, showers with functions to monitor water quality (pH, chlorine level, turbidity)
- AMRs installed at the water inlets and outlets for water usage metering and to monitor leakage.
- Data from AMRs and wireless sensors are transmitted to a concentrator and then forward to through the internet / intranet and stored in the servers at Postgraduate Lab, Building 1.
- Authorized personnel are able to access the data from the server through internet or intranet.

Figure below shows the system architecture of TWMS:

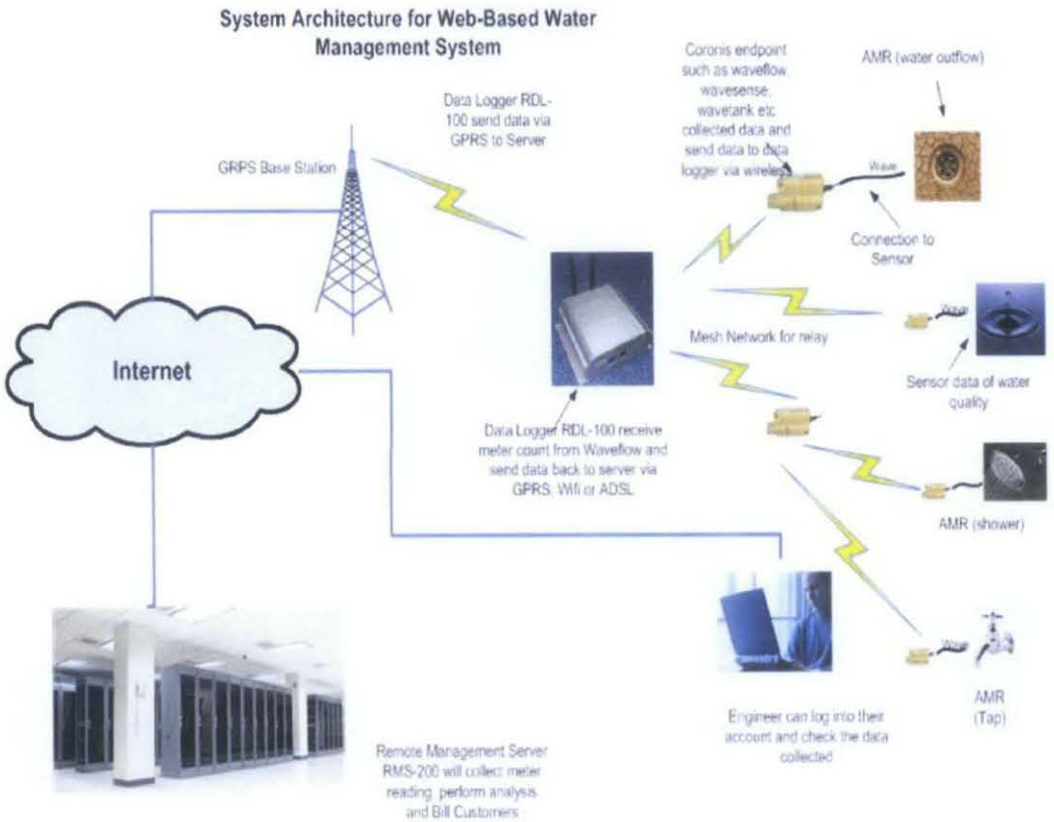

Figure 12: System Architecture of TWMS

However, until the date of this report is written, the required sensors for the project have yet to be delivered by the vendor. This is due to the research grant applied has getting a positive reply. Hence, payment cannot be done to the vendor for the sensors. Without the sensors, the 2nd and 3rd phase had not been carried out. The idea and architecture is however feasible and will be followed in future execution of this 2nd phase.

3.3 TWMS Web Application Development

The web application is built under the agile development methodology, where the project being developed in incremental, repetitious means.

The development starts by identifying the objectives of the project. The objectives identified are as stated in Chapter 1, and the second stage is to visualize major scenarios that users will be in, for example, the way potential users will use the application, the data users wish to see, how users will navigate, etc.. After having an idea on the major scenarios, the flow and views of the application is designed. Next, development starts with efforts to identify major parts of the application and emphasis being put into these important sections.

The cycle of development is repetitive as all sections developed will be review continuously to identify element of enhancement and refinement that comply with the project's objectives. Figure below shows the general agile development cycle:

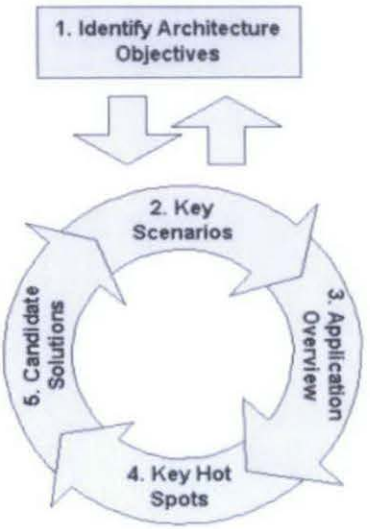

Figure 13: Agile Development

The application is developed under .NET environment using ASP.NET. The reason of choosing .NET is that the developer(s) is more familiar with the technology compare to other open source languages. Besides, built-in functions and modules in the ASP.NET are much more user-friendly.

The prototype is running in the Windows Server 2008 R2 operating system with Microsoft SQL Server 2008 R2 as backend database and it is being hosted by the Internet Information Services (IIS). The entire environment is Windows / Microsoft based. This is due to easier integration and management, compare to a system with various open source product. For example a Java-based application with Apache Derby database that is hosted by Glassfish Application Server on a Linux operating system. Windows Server 2008 R2 and Microsoft SQL Server 2008 R2 provides an interface that enable ease of management. Besides, the IIS is a role in the Windows server operating system and hence, no external application server / web server is needed.

Deployment of this web application is relatively easy by pushing "Publish" button in Microsoft Visual Studio and transfers the files to IIS. Next, create an application pool for the website and it is ready to run. All computers within the same network range are able to access the website using their web browser.

Below are some screen shots of the web application:

Figure 14: Application Screen Shot 1

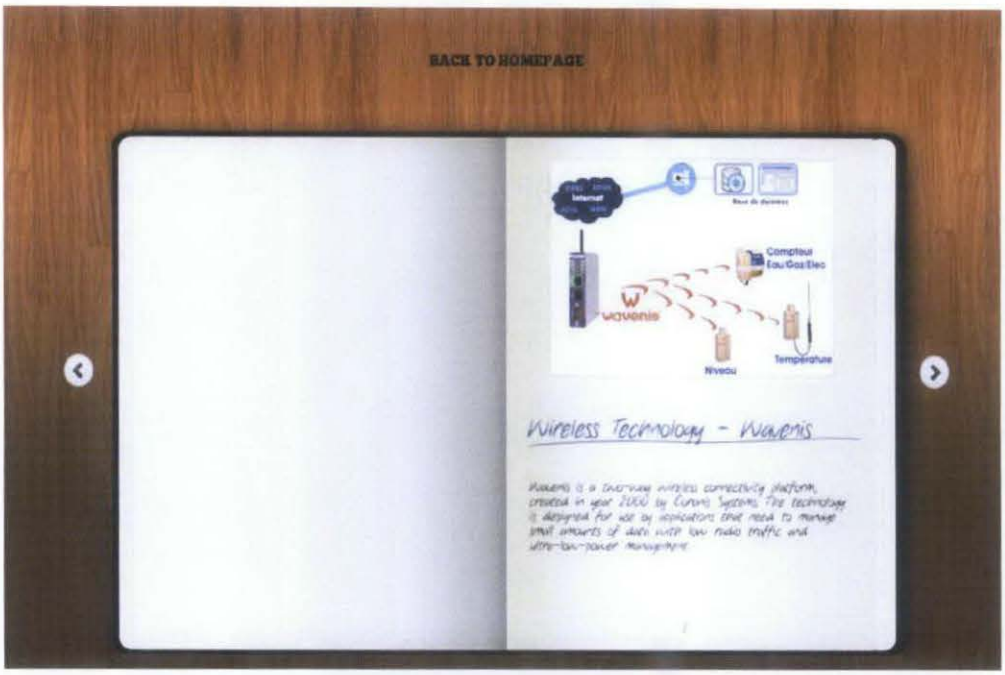

Figure 15: Application Screen Shot 2

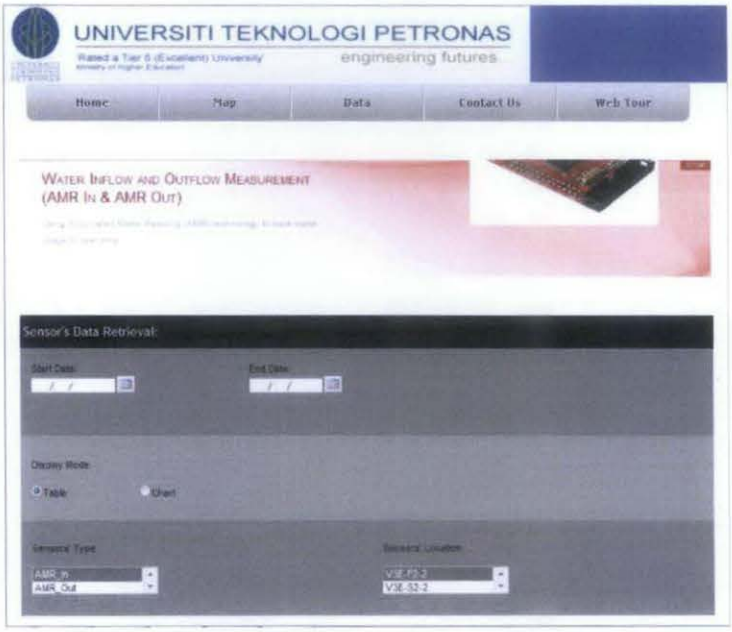

Figure 16: Application Screen Shot 3

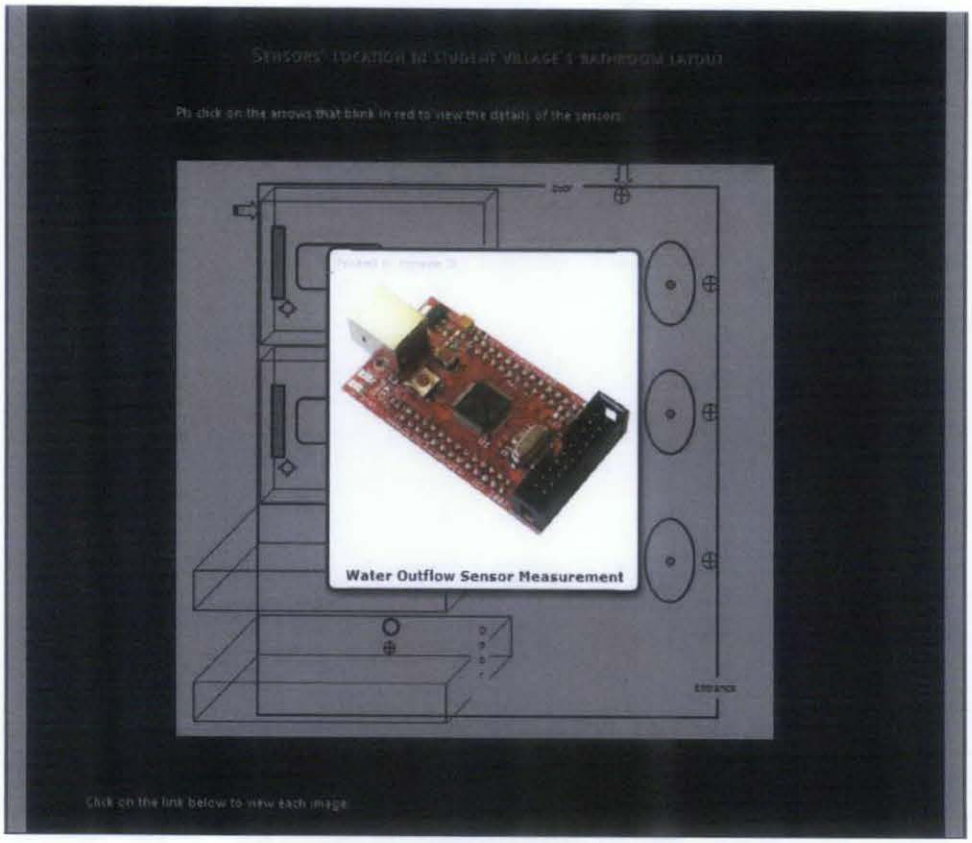

Figure 17: Application Screen Shot 4

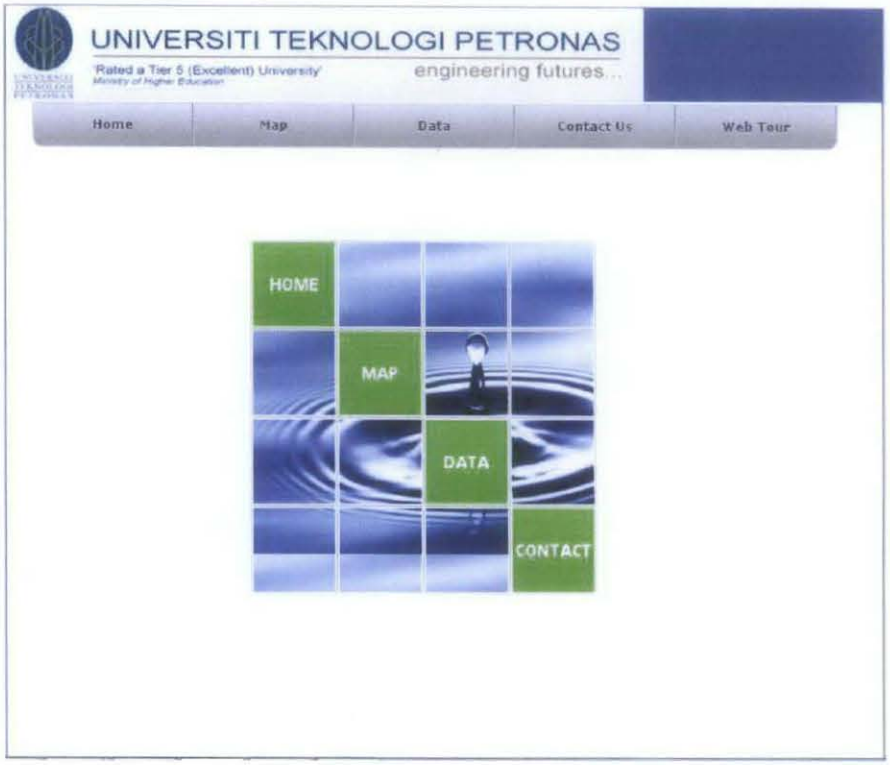

Figure 18: Application Screen Shot 5

Data will be collected for analysis to prove that TWMS provides a more efficient and effective method of water management. With the data in hand, authority on the water resource can make better decisions regarding the water quality and usage of the particular organization.

Data on the pH level, chlorine level, and other traits will be benchmarked with the national standard to make sure water quality of the university is at the safe level. The water usage pattern in the university is compared with the suggested usage volume to identify potential leakages or wastage of water in the residential villages.

In order to make the raw data collected more presentable and easily understood by any layman, a web-based program will be developed. The web-based program is used to translate raw data collected in to meaningful presentation that any layman would see and understand. The reason that the program is made web-based is because the TWMS should be accessible by authorized personnel anytime, anywhere. Hence, web-based program is the most suitable option in developing it.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Major Deliverables

The main deliverables of the project is the web-based application developed. The application is developed for more efficient water resource monitoring and controlling in the areas of usage, quality and leakage. Series of screens below will explain the web application:

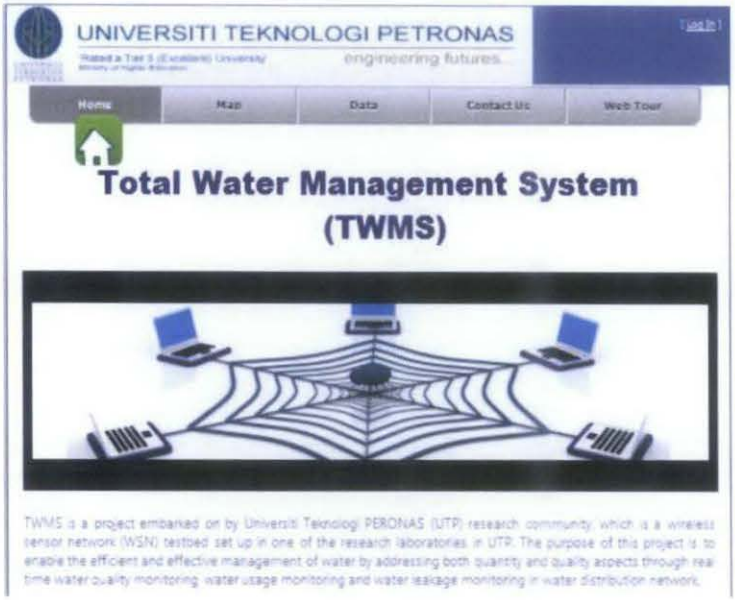

Figure 19: Homepage

Figure 19 shows the landing page of the Total Water Management System (TWMS). Whenever users navigate to TWMS's page, this will be the first page they will see. The homepage has a paragraph of explanation on the TWMS and related information.

At the bottom of the page, there is another link as shown in Figure 20 that will bring the user(s) to a new page if the user(s) wish to gain more technical information about TWMS.

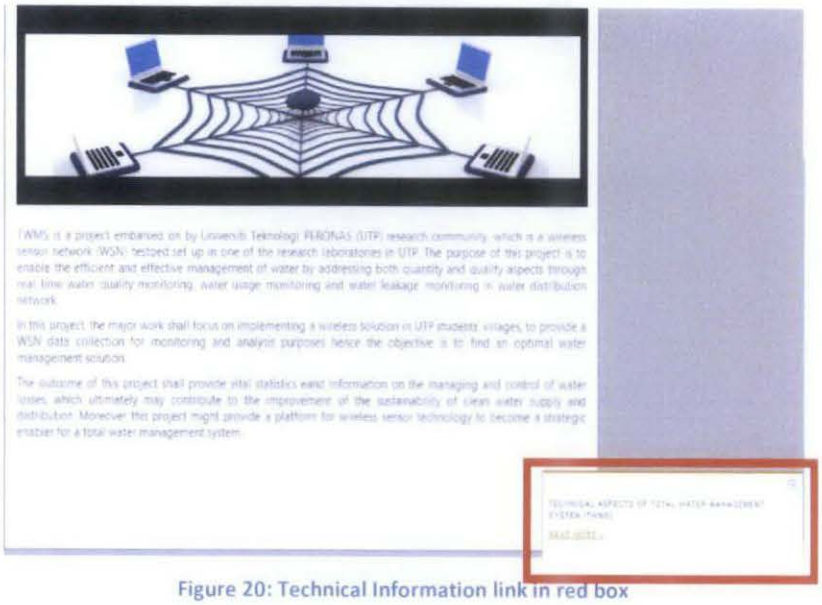

Figure 20: Technical Information link in red box

Upon clicking on the link, user(s) will be brought to a new page similar to Figure 21 that he/she can read through technical information of TWMS.

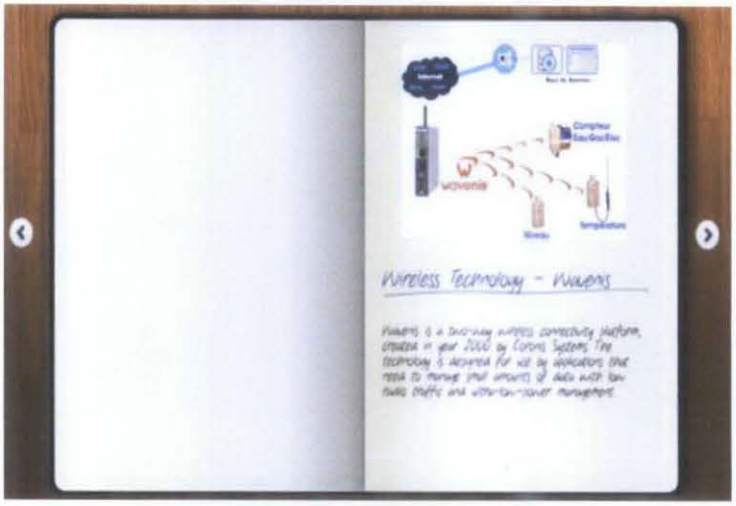

Figure 21: Technical information of TWMS

The user(s) can go back to the homepage by clicking "Back to Homepage" link. Under the "Map" tab on the navigation bar, user(s) can see the layout of the test bed and user(s) can locate the location of sensors installed, as in Figure 22.

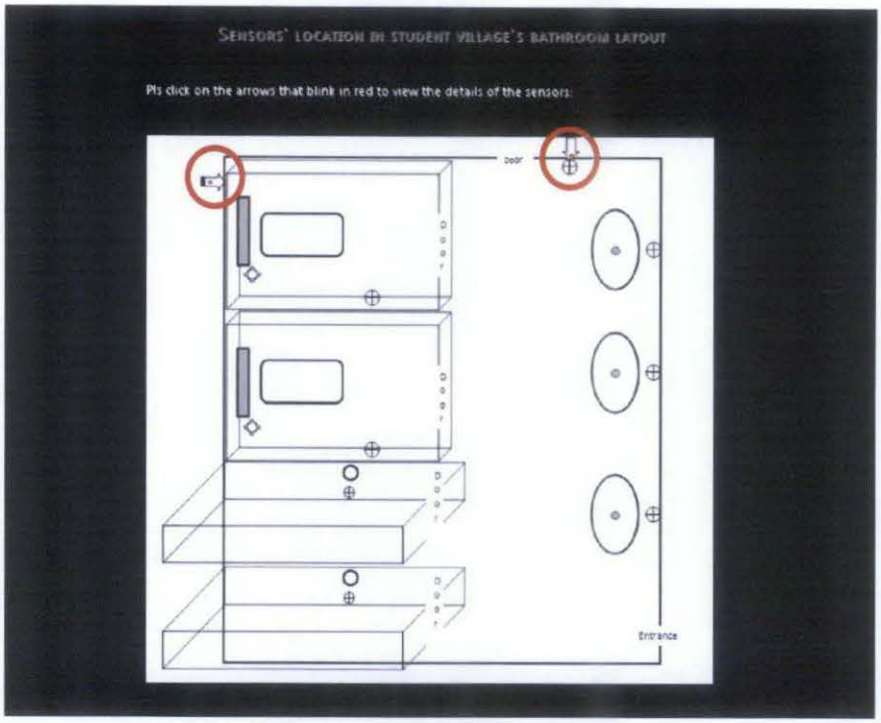

Figure 22: Layout and location of sensors

From Figure 22, user(s) can click on the sensors' location (as in red circle) and an image of the sensor used will pop-up.

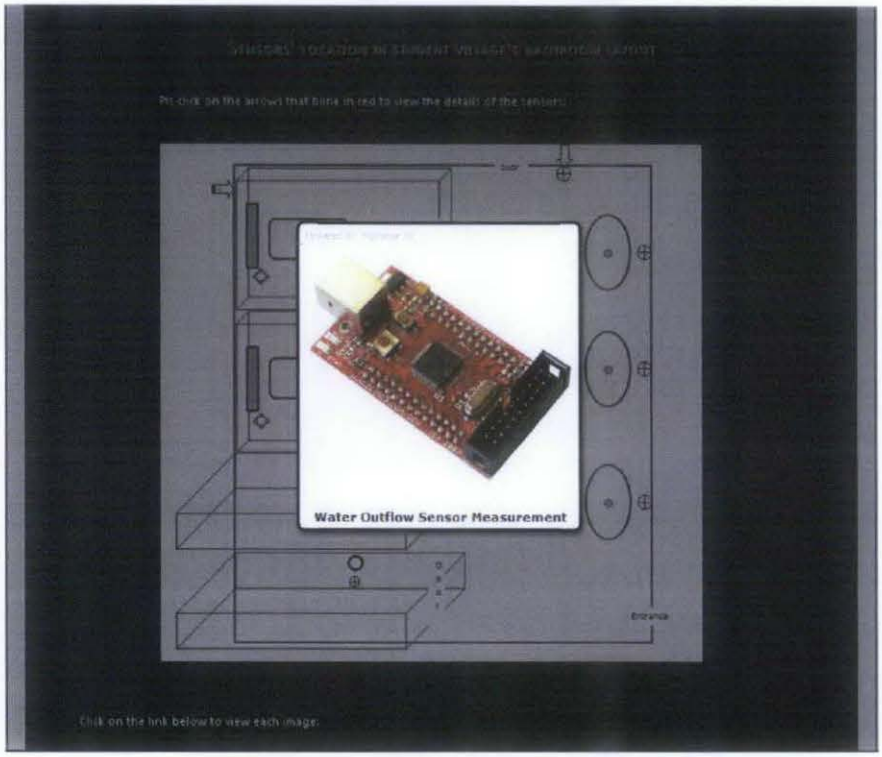

Figure 23: Sensor image

The main functionality of the TWMS will be under the "Data" tab, where user(s) basically monitor and analyse data collected by the sensors in the test bed. On the data page, user(s) can select the student village that he/she wishes to monitor and select to monitor water usage / leakage or water quality.

For water usage, user(s) can select to view data in table form of in bar chart. Water usage data are collected by the sensors installed at the water inlets. Figure 24 below shows water usage data being displayed in table form and data can be exported to excel sheet for other administrative purposes. Figure 25 shows data being displayed in bar chart and it can be exported as an image file.

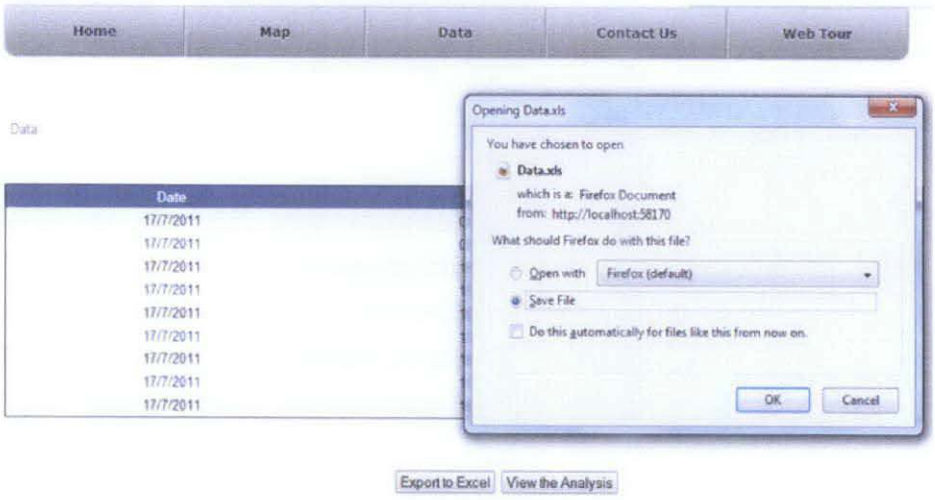

Figure 24: Water usage data in table form

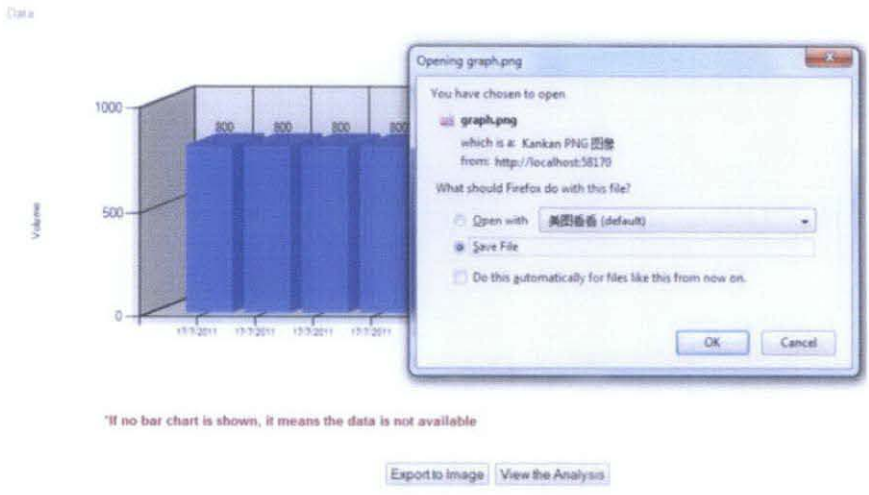

Figure 25: Water usage data in bar chart

User(s) can also monitor water leakages from the application. Water leakages are calculated in the simple formula below:

$$\text{Volume}_{\text{Leakage}} = \text{Volume}_{\text{Inlet}} - \text{Volume}_{\text{Outlet}}$$

The system will use the records of water inflow sent by sensors at the water inlets to subtract with the records of water outflow sent by sensors at the water outlets to gain results of water leakages. The water leakages data will be showed in table form on the application and a pie chart is displayed below the table that separates water leakages according to the village floors. Figure 26 shows the screen of the water leakage data being displayed.

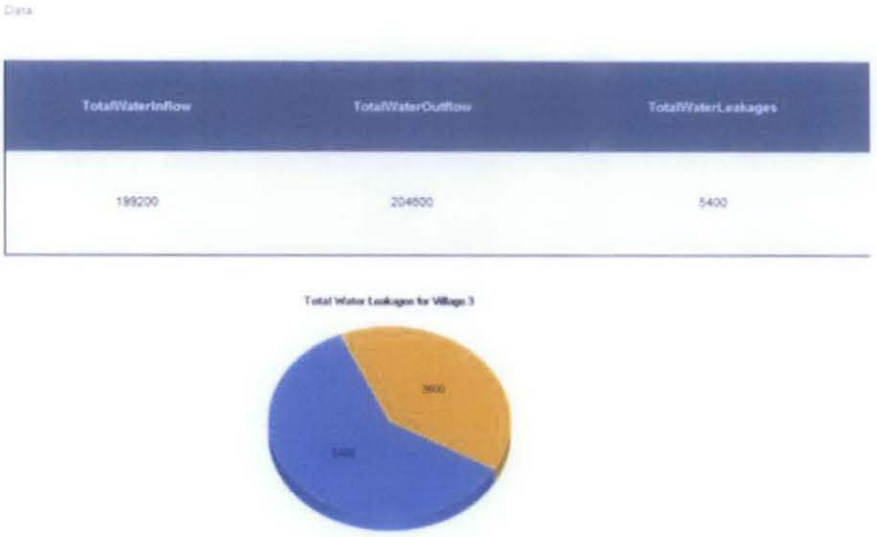

Figure 26: Water leakages data

Next, water quality measures can be monitored. The parameter that the system will measure to date is water pH. Sensors measuring water pH are installed in various locations at the test bed and they will transmit water pH data to the server. The water pH data will be displayed in a line graph as shown in Figure 27.

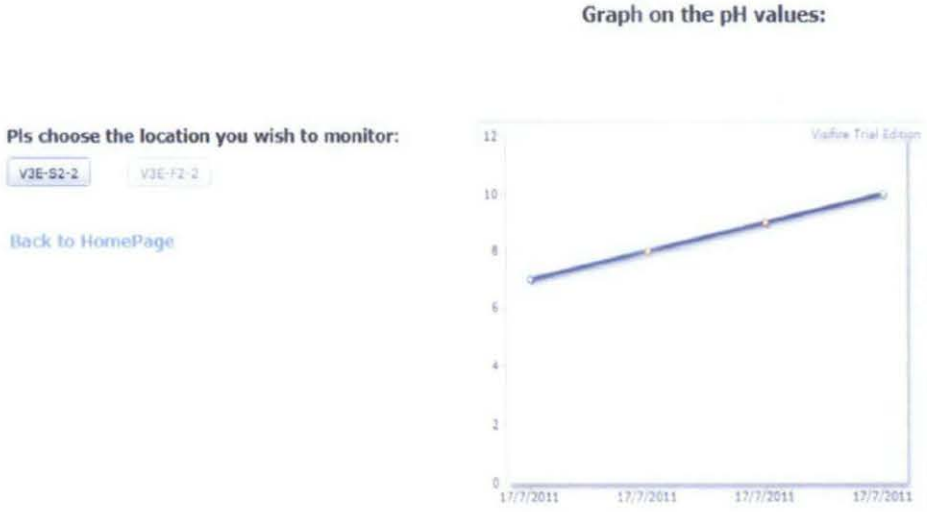

Figure 27: Water pH data

The water quality monitoring is important in the sense that it tells whether the water is safe for consumer usage. Immediate actions are required if water quality is found to be in the unsafe range. Hence, the application is designed to send a notification e-mail to the administrator / maintenance personnel when the quality falls into unsafe range. For the water pH, an e-mail is sent when it drops under pH 6.0 or exceeds pH 8.0 from the data collected.

With the functionality above, the application had it objectives covered. It can monitor the water resource usage, water resource leakage and water resource quality. The application is web-based and hence it can be accessed anytime, anywhere as long as there is an internet connection, after the application is published to the internet.

4.2 Problems faced in the project

In the process of executing the TWMS project, there are various problems being encountered. The major problem is the development platform. The difference in development platform of the TWMS had made the application unable to be hosted in the existing environment in Universiti Teknologi PETRONAS (UTP) laboratory in Building 1. The existing environment was setup by the hardware vendor to accommodate the Java platform software, but TWMS was developed using .NET platform. The table below shows the different between TWMS and the CornusView which is Java-based software in the existing environment.

	CornusView	TWMS
Server Operating System	Linux	Windows Server 2008 R2
Software Language	Java	ASP.NET
Application Server	Glassfish Application Server	Internet Information Services (IIS) – a role in Windows Server 2008 R2
Database	Apache Derby	Microsoft SQL Server 2008 R2

Table 5: CornusView and TWMS comparison

The existing environment are utilizing all open source products, that lead to potential difficulties in integration works in later phases especially wanted to deploy a .NET application to the environment. Besides, the sensor boards and concentrators are all configure to communicate with Java-based application and Linux operating system. Employing the existing environment may require developers to reprogramming firmware, which the developers had no experience in.

Another problem is that information provided by the hardware vendor is limited. This had resulted in the painful process of integration and ultimately a new environment is setup and the hardwares are barely utilized. Lastly, the extended time period of research grant approval had led to the postponement of the new sensor boards' purchase. This had affected the 2nd phase of the project to installing the sensors in the test bed for real data collection.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study has described the implementation of a total water management system that uses wireless sensor network to manage water more efficiently and effectively by addressing both quantity and quality aspects through real time water quality monitoring, water usage monitoring and water leakage monitoring in water distribution network. The overall study is directed towards four main goals: 1) the application of a low cost wireless sensor network for high data rate and online monitoring within a large area; 2) the development of systems to enable remote detection of leaks and turn on or off the valves; 3) real time monitoring of water usage; 4) remote online monitoring of water quality. So far, this total water management system is the first in-situ test bed deployed in Malaysia to gather and process data continuously on a real water distribution system.

This effective and efficient method for managing scared water resource is believed to gain vast supports and implementations in future especially by large organizations and buildings. Administrators / maintenance personnel will be able to gain firsthand information remotely from the integrated system and take immediate action without going on-site to monitoring water resource and taking samples for quality experiments.

5.2 Recommendations

The Total Water Management System is a project of high potential and below is some recommendations for future enhancement:

a) Measures more water quality parameters such as turbidity, colour and chlorine level by adding more sensors to the architecture
b) Expands deployment scale to include more villages to be monitored under TWMS
c) Utilize the sensors in predicting pipe burst events

d) Enhance the notification method in the web application. Instead of sending e-mail, send notification SMS to the administrator / maintenance personnel

An interesting study that can be done upon deployment of the Total Water Management System is to collect and analyse data on water usage pattern of males and females in the campus. The study can lead to more understanding on water usage and wastage of both genders, and results in more efficient usages and decreasing wastage by both genders.

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