Review of Real-time Data Transmission Systems for Slope Instrumentation

GEO Report No. 262

C.S.C. Tang & S.P.Y. Cheung

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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This report is largely based on GEO Technical Note No. TN 2/2009 produced in June 2009

Table of Contents
Table of Contents
Table of Contents
Table of Contents

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First published, October 2011

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Table of Contents
Table of Contents
Table of Contents

Preface

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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Y.C. Chan
Head, Geotechnical Engineering Office
October 2011

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Foreword

This report consolidates GEO's recent experience in the application of real-time data transmission systems in slope instrumentation projects. The relative reliability and advantages of the respective data transmission technologies are discussed and recommendations for further work are made with a view to enhancing GEO's capability in real-time slope monitoring.

This report was prepared by Chris S.C. Tang and Sammy P.Y. Cheung of the Standards & Testing Division. Mr Eddie Chan and Mr Stuart Millis of Ove Arup & Partners Hong Kong Limited provided useful reference materials on the instrumentation work under Contract No. GE/2006/10. Mr Eric Ho of FT Laboratories Ltd. and Mr W.M. Chan of Fugro Geotechnical Services Ltd. made available valuable information related to the technologies behind the data transmission systems developed by their respective companies. All contributions are gratefully acknowledged.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

Abstract

Different real-time instrumentation systems have been adopted in seven GEO projects in the past few years. A review of these real-time data transmission has been conducted to consolidate GEO's experience on the application of the different systems and to examine the technologies that are available in Hong Kong and adopted in real-time data transmission systems. A modern real-time data transmission system should utilize devices and technologies that are resilient to failure and consume less power in order to minimise maintenance efforts. Such systems usually include geotechnical instruments on sensor nodes, a local wireless network, base stations and an information system as have been adopted in four GEO projects.

In this report, the technical details of the seven GEO projects are presented and their performance discussed. In general, the overall performance of the systems is satisfactory in that they were able to capture the real-time data during severe rainstorms. However, the review has also identified some data losses due to factors such as bad weather, internal program bugs and delays in taking remedial maintenance action. Based on the observations and findings, some potential areas of improvement in the future use of the real-time data transmission systems and development work by GEO are suggested for consideration.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Contents

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

List of Tables

Table of Contents
Table of Contents
Table of Contents
Table of Contents

List of Figures

Table of Contents
Table of Contents
Table of Contents

1 Introduction

Conventionally, monitoring data in slope instrumentation are collected manually on site using hand-held equipment or dataloggers. The frequency of monitoring depends on the resources available and the needs of the projects. Measurements are taken at the specified intervals. In some projects, automatic devices are installed to capture the data, typically at a high frequency. The data are stored in the local memory module of the device. However, it would still be necessary to manually retrieve the data from the instruments and hence there is a time lag between the data captured on site and the time that they are interrogated by the data users.

In recent years, the mobile and wireless technology has advanced considerably and the telecommunication infrastructure and coverage of mobile services have effectively penetrated most parts of Hong Kong. Real-time data transmission systems capitalizing on advanced mobile and wireless technology have become feasible and commercially viable options. Such technologies are particularly suitable for use in geotechnical instrumentation in general and slope instrumentation in particular, as the locations of the monitoring stations are often in areas where it is difficult and probably expensive to lay land-based datalines. The use of land-based datalines also suffers from a number of shortcomings that affect the stability and reliability of data transmission (Strout et al, 2008). A number of local geotechnical instrumentation contractors have developed real-time data transmission systems for use in slope instrumentation work.

GEO has examined the application of real-time slope instrumentation as a risk management tool in slope engineering. Wong et al (2006) discussed the potential applications of slope instrumentation and key factors that need to be addressed in order to ensure the effectiveness of an instrumentation system, with particular reference to Hong Kong's circumstances. Typical applications of an instrumentation system can generally be categorized as follows:

(a) assessing and designing slope works,

(b) enhancing technical knowledge,

(c) health monitoring of slope stabilization and risk mitigation measures,

(d) monitoring of landslide sites, and

(e) providing real-time regional or site-specific warning.

Real-time slope instrumentation systems have been adopted in a number of GEO projects (Table 1.1). Real-time data transmission systems provide data users with the captured data within a reasonable timeframe (typically within minutes to hours). It should be borne in mind that any remote monitoring systems will have a time delay between data sampling and display. However, this would be adequate to users, provided that the data represent the current field condition.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1.1 Recent GEO Projects Involving Application of Real-time Data Transmission Systems for Slope Instrumentation (Sheet 1 of 3)

	Slope No. 11NW-B/C136, above Lion Rock Tunnel Road	Slope No. 15NE-B/FR31, below Shek O Road	Distressed Hillsides at Kwun Yam Shan
Objective of the slope instrumentation	Assessing and designing slope works	Health check and monitoring effectiveness of slope improvement works	Health check and monitoring effectiveness of slope improvement works
Service provider supplying the real-time data transmission system	FT Laboratories Ltd.	FT Laboratories Ltd.	Fugro Geotechnical Services Ltd.
Instruments installed	8 automatic piezometers	3 rod extensometers, 3 in-place inclinometers, 12 tell-tale markers	4 automatic piezometers, 10 in-place inclinometers
Real-time data transmission system	Wireless Sensor Network (WSN)	Wireless Sensor Network (WSN)	Real-time Wireless Geotechnical Monitoring System (RADAS)
Technology for local area network	ZigBee	ZigBee	ZigBee
Wireless telemetry services for wide area network	HSPA	HSPA	GPRS
Frequency of data capture	15 minutes	15 minutes	Hourly
Relational Database Management System	Sybase	Sybase	Oracle
Information System	Web-based application (DeMon) developed based on JavaServer Pages (JSP)		Web-based Geotechnical Instrumentation Monitoring System (GIMS)
Alert criteria and planned actions	No alert criteria specified	No alert criteria specified	No alert criteria specified

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1.1 Recent GEO Projects Involving Application of Real-time Data Transmission Systems for Slope Instrumentation (Sheet 2 of 3)

	Landslide Preventive Works at Po Shan Road, Mid-levels	GEO Raingauge System	Instrumentation Works under GE/2006/10
Objective of the slope instrumentation	Health monitoring of the stabilization measures	Regional warning system	Technical development
Service provider supplying the real-time data transmission system	Fugro Geotechnical Services Ltd.	System developed in-house by GEO	Sol Data (Asia) Ltd.
Instruments installed	52 automatic piezometers	86 automatic raingauges	See Table 1.2
Real-time data transmission system	Real-time Wireless Geotechnical Monitoring System (RADAS)	GEO Raingauge System	Instrumentation Monitoring Database System (IMDS)
Technology for local area network	ZigBee	Not Applicable	Not Applicable
Wireless telemetry services for wide area network	GPRS	GPRS	GPRS
Frequency of data capture	5 minutes	5 minutes	Varies, but generally within 15 minutes
Relational Database Management System	Oracle	Oracle	RDBMS Firebird Version 2 and Oracle 11g
Information System	Web-based Geotechnical Instrumentation Monitoring System (GIMS)	Web-based GEO Raingauge System	Dedicated Programme Geoscope Web (GW)
Alert criteria and planned actions	Groundwater level exceeding predetermined level work trigger automatic alerts to specified personnel via SMS	Landslip Warning level based on predicted number of landslides for consideration of issue of Landslip Warning	Email alert is triggered when values exceed specified values based on the existing monitoring data

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1.1 Recent GEO Projects Involving Application of Real-time Data Transmission Systems for Slope Instrumentation (Sheet 3 of 3)

	Debris Flow Detection System at Tung Chung
Objective of the slope instrumentation	Technical development
Service provider supplying the real-time data transmission system	Fugro Geotechnical Services Ltd.
Instruments installed	6 nos. tilt sensors in 2 array 2 nos. vibration sensors
Real-time data transmission system	SMS alert message
Technology for local area network	N/A
Wireless telemetry services for wide area network	GSM SMS
Frequency of data capture	N/A
Relational Database Management System	N/A
Information System	N/A
Alert criteria and planned actions	When the tilting angle on steel post exceeds 15 degree from vertical or the ground vibration sensor reading exceeds 3 to 5 volts; the system automatically sends an SMS alert to specified personnel

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1.2 Types of Sensors Installed on 4 Natural Hillsides at 4 Sites Under Contract No. GE/2006/10

	Tsing Shan Foothills, North West New Territories	Tung Chung Foothills, Lantau Island	Pa Mei, Lantau Island	Ching Cheung Road, Kowloon
Surface Movement	▪ 1 no. horizontal time domain reflectometry ▪ 4 nos. GPS monitoring station ▪ each GPS station with 6 nos. antenna	▪ 1 no. crackmeter	▪ 1 no. crackmeter ▪ 8 nos. tension, rotation & settlement (TRS) sensor	▪ 3 nos. inclinometer
Sub-surface Movement	▪ 1 no. inclinometer ▪ 7 nos. in-place inclinometer (each with 5 levels of sensor) ▪ 2 nos. time domain reflectometry (TDR) ▪ 2 arrays earth pressure cell	▪ 1 no. inclinometer ▪ 2 nos. in-place inclinometer (each with 4 nos. sensor) ▪ 2 arrays earth pressure cell (each with 2 nos. sensor)	▪ 2 nos. inclinometer ▪ 6 nos. in-place inclinometer (each with 5 nos. sensor)	
Hydrogeological Monitoring	▪ 3 arrays time domain reflectometry (WTDR) soil moisture probe (each with 3 nos. sensor) ▪ 3 arrays jet fill tensiometer (each with 3 nos. sensor) ▪ 3 nos. multi-level groundwater monitoring sensors ▪ 7 nos. single groundwater monitoring sensor	▪ 2 arrays WTDR soil moisture probe (each with 3 nos. sensor) ▪ 2 arrays jet fill tensiometer (each with 3 nos. sensor) ▪ 1 array thermal conductivity suction sensor with 3 nos. sensor ▪ 3 nos. multi-level groundwater monitoring sensors ▪ 6 nos. single groundwater monitoring sensor	▪ 4 arrays WTDR soil moisture probe (each with 3 nos. sensor) ▪ 3 nos. multi-level groundwater monitoring sensors ▪ 6 nos. multi-level groundwater monitoring sensors ▪ 5 nos. single groundwater monitoring sensor	▪ 8 nos. inclinometer ▪ multi-level groundwater monitoring sensors ▪ 6 nos. single groundwater monitoring sensor
Environmental Monitoring	▪ 1 no. site-specific tipping bucket raingauge	▪ 1 no. site-specific tipping bucket raingauge	▪ 1 no. site-specific tipping bucket raingauge ▪ 1 no. evaporimeter ▪ 1 no. v-notch weir	▪ 1 no. site-specific tipping bucket raingauge

Table of Contents
Table of Contents
Table of Contents
Table of Contents

This report consolidates GEO's experience in the application of real-time data transmission systems, with particular emphasis on the technologies adopted in the different systems, together with their performance and reliability. Based on the experience gained, some areas for improvement are suggested.

2 Previous Work by GEO on Data Transmission

Chan & Wong (2001) documents the feasibility study of three automatic piezometric data acquisition systems. One of the systems adopted manual download of the monitoring data and no real-time data transmission system was used. Therefore, its details are not discussed in this report. The other two systems included real-time transmission modules based on the use of fixed telephone lines and VHF radio waves. The automatic acquisition systems comprised downhole pressure sensors for measuring groundwater levels and a datalogger at the top of the borehole. Trial tests were undertaken between July 1999 and October 2000, with the monitoring data obtained at 5-minute intervals for the piezometers. The report by Chan & Wong (op cit) concludes that both means of data transmission were fairly reliable. During the trial period, data loss were reported to range from 7% to 12% for data transmission by means of telephone lines, and about 2% for data transmission using radio waves. The causes of data loss were mainly related to excessive power consumption on the electronic modules which drained the battery, breaking down of the telephone lines, flat battery, and data spikes induced by lightning during thunderstorms. The report does not give any information on the time delay between data capture and the time when the data are made available to users.

GEO commissioned Fugro Scott Wilson Joint Venture to conduct a review of slope movement monitoring techniques, which included automatic data acquisition systems. The report by FSWJV (2005a) gives an overview of the various types of data transmission technologies, including mobile, wireless and cabled transmission and discusses briefly the real-time transmission systems that have been adopted for various Hong Kong projects. FGS (2007) gives more detailed descriptions on the communication protocols that are applicable in providing real-time data transmission between dataloggers and remote servers. The report also suggests further review of the possible use of the monitoring standard promulgated by the Association of Geotechnical and Geoenvironmental Specialist for transmitting the data, together with the standard eXtensible Markup Language (XML) for data exchange between computers.

GEO also reviewed the practicability and reliability of a real-time data transmission system (i.e. Real-time Drilling Process Monitoring System, RT-DPM) developed by E-business Technology Institute of the University of Hong Kong. RT-DPM incorporated the Drilling Process Monitoring technique with real-time monitoring capability and the drilling data was transmitted to a site server via GPRS mobile network. The data could then be accessed on a designated website via the Internet. A trial use of the system was conducted on the drilling works of 110 soil nails at a LPM site at Sham Tseng in 2006. The trial indicated that RT-DPM was reliable in providing real-time drilling data on site, and it was suggested that the digital wireless data transmission method of RT-DPM could be considered for wider application for other geotechnical instrumentations (Lai & Lo, 2007). RT-DPM is different from a slope instrumentation system that is installed to regularly capture site data for a longer period. It is applied to monitor the drilling process of soil nailing works during

Table of Contents
Table of Contents
Table of Contents
Table of Contents

construction, whereby the arrangement of power supply and technician support to maintain the RT-DPM is comparatively easier. However, the site environment in this case could be more variable, as there would be a lot of activities in progress and any interference to the system might jeopardise the reliability of the data transmission system. For example, the system has to be re-configured each time the equipment is moved to a new position along with the drilling rig.

3 Overview of Real-time Data Transmission Systems

3.1 General

A modern real-time slope instrumentation system generally comprises the following four key components:

(a) sensor nodes which consist of instruments and a datalogger,

(b) communication network for sensor nodes,

(c) base station with an external communication modem, and

(d) information system for consuming the data.

3.2 Sensor Nodes

A sensor node represents the combination of an instrument and a datalogger installed at a monitoring station. Dunnicliff (1993), Geoguide 2 (GEO, 1987) and Spalton et al (1998) compare various types of instruments that are commonly used in slope engineering practice, such as piezometers, inclinometers and extensometers. FSWJV (op cit) discusses the operational principles of the various instruments for measuring slope movement and groundwater pressure. Most of the instruments measure the changes in electrical properties, such as potential difference (voltage) or electric current, which are then converted to give the ground displacement, distortion, or groundwater pressure, as appropriate. The changes in these electric properties are usually brought about by variations in magnetic field, natural frequency, electric resistance or conductivity due to displacement or elongation of the embedded elements of the instrument.

A datalogger is an electronic device that collects signals from the monitoring instruments. An instrument typically sends analog signals, which are continuous signals of some electrical properties that vary with time. The disadvantage of an analog signal is that the system invariably contributes noise, and any amplification and filtering will affect the noise as well as the analog signals themselves. Poor reception of analog signals could be improved by using digital signals. A datalogger usually includes multiple channels for connecting to an array of instruments, including both analog and digital signals. In addition, an analog-to-digital converter is commonly incorporated in the circuit board, which converts analog signals to discrete-time sampled or bit-stream digital signals for onboard data processing and manipulation by the microprocessor in the datalogger. With recent advancement in miniaturisation technology, a datalogger can now be made with a small form

Table of Contents
Table of Contents
Table of Contents
Table of Contents

factor (Figure 3.1), which comprises a microprocessor, data storage capacity, a transceiver with antenna and a power supply unit.

The instrument and the datalogger in a sensor node are usually connected by means of a cable within a borehole. Where it is necessary to install a number of instruments at various depths in a borehole (e.g. in-place extensometers and inclinometers), a multiplexing system may be used to connect the datalogger to the instruments installed at various depths via a single cable. Such arrangement can allow the installation of more instruments within a borehole.

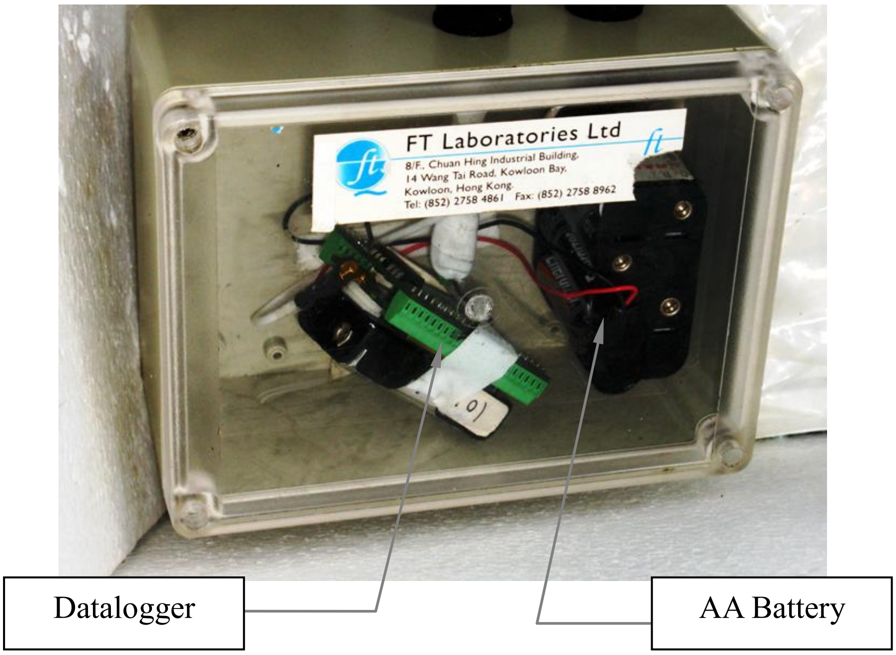


Figure 3.1 Datalogger and Wireless Transmission Based on the Use of ZigBee Technology (WSN by FT Laboratories Ltd.)

3.3 Sensor Network

Where it is necessary to install a number of sensor nodes in a site, a sensor network is usually set up for routing the data from individual sensor nodes to a base station (sometimes referred to as a gateway sensor node). A range of different technologies is available for setting up the sensor network. These include cabled and wireless connection such as Wi-Fi, Bluetooth, ZigBee, etc. ZigBee technology has been adopted in two separate systems (RADAS and DeMon respectively) developed by local geotechnical instrumentation contractors, and has been used in four LPM sites (see Table 1.1). A comparison of the functionality and efficiency of the various wireless protocols is given in Table 3.1.

The ZigBee wireless standard (IEEE Standard 802.15.4) was promulgated by the Institute of Electrical and Electronic Engineers (IEEE) for use in smart devices. Sensor nodes to ZigBee standard usually have ultra low power consumption and a small form factor.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

In addition, the network protocols based on ZigBee standard allow the sensor nodes to be 'self-organizing' in the network, as the sensor nodes can communicate with the neighboring sensor nodes and look for the most optimized path (i.e. the shortest route) of packet forwarding based on the routing algorithms. Alternate routes can be established automatically, should any individual sensor nodes become unavailable for passing on the data. The sensor nodes can be deployed at random but they should be within the hopping ranges of the adjoining sensor nodes. Usually, a line of sight (in the context of radio waves) would be required to establish communication between adjacent sensor nodes. However, repeaters (i.e. a sensor node without connection to instruments) may be added to establish a connection round obstacles in the field.

Table 3.1 Comparison of Common IEEE Wireless Protocols

Property	IEEE Standard		
	802.11 a/b/g/n	802.15.1	802.15.4
Operating band	2.4/5 GHz	2.4GHz	2.4 GHz
Common name	WiFi	Bluetooth	ZigBee
Optimal operational range (m)	~ 100	~10 to 100	~10
Data throughput (Mbps)	~2 to 270	~1 to 3	~ 0.25
Power consumption	Medium	Low	Ultra-low
Battery life	Minutes to hours	Hours to days	Days to years
Size relationship	Large	Smaller	Smallest

The capability of self-organizing the routing path increases the resilience and reliability of the sensor network. However, such capability is also a function of the network topology deployed, in that the adjoining sensor nodes must be within the hopping range. Commonly used network topologies are shown in Figure 3.2. A mesh topology usually provides the best resilience to failure of individual sensor nodes, because alternative transmission routes could be established automatically to bypass the faulty sensor node. The network topology could comprise multiple base stations in order to enhance system reliability and provide a redundancy. The ZigBee technology can support up to 255 sensor nodes in a

Table of Contents
Table of Contents
Table of Contents
Table of Contents

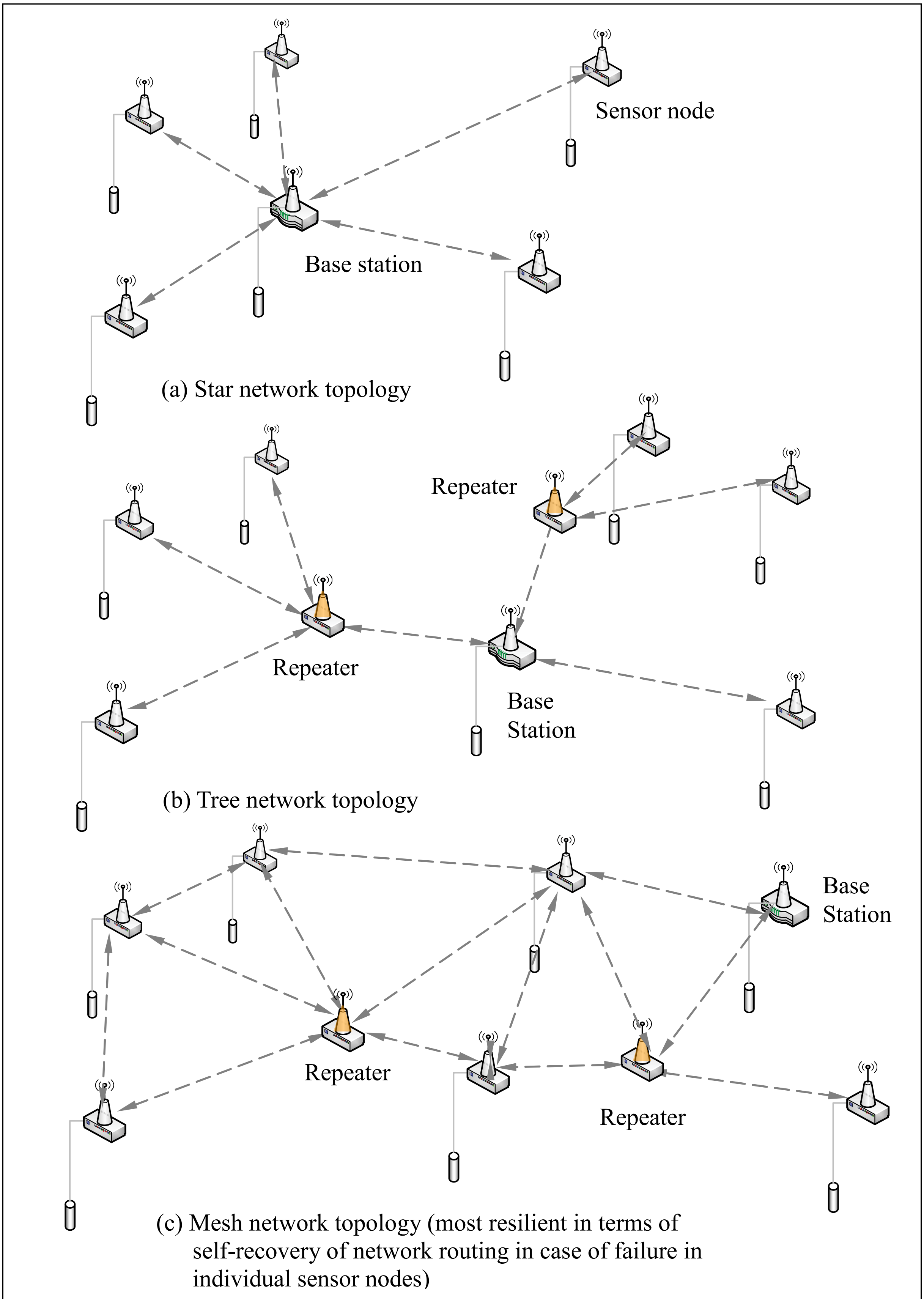


Figure 3.2 Common Network Topology for Wireless Sensor Network Based on ZigBee Standard

Table of Contents
Table of Contents
Table of Contents
Table of Contents

simple network topology, but it can theoretically be extended to a maximum of 64,000 sensor nodes.

The data throughput rate using the ZigBee technology is only limited to 250 kbps. Such transmission rate will be degraded, however, when the distance between sensor nodes is increased. Therefore, sensor node using ZigBee technology is suitable for transmitting text and graphic data but it is not suitable for streaming video and high definition pictures where high volumes of data are involved. In the latter cases, data transmission using the third-generation mobile technology (e.g. WCDMA and HSPA) would be more suitable. Details on ZigBee standard are given by Sohraby et al (2007) and Baronti et al (2007).

Devices based on Wi-Fi and Bluetooth wireless technology offer the capability of a high data transmission rate. However, they are not common in instrumentation network in remote sites because of power consumption requirements. Bluetooth technology usually requires devices to be located within a range of 10 m for reasonable power consumption. The maximum range could be increased to 100 m, but this would be at the expense of higher power consumption. The Wi-Fi technology is suitable for the setting up of a local area network, but it would normally require a cabled connection for establishing the final connection to the Internet. Recently, mobile Wi-Fi routers are available in the market, which incorporate the mobile telemetry services (e.g. HSPA) within the device for connection to the Internet.

The necessity of deploying a sensor network in an instrumentation system depends on the network topology of the instrumentation system. Individual sensor nodes can be configured to directly transmit data to the information system by establishing a wide area network (WAN) with an external communication modem. For such arrangement, each sensor node becomes a base station attached on the WAN. This topology is suitable for monitoring systems where only a single instrument is installed at each site, e.g. GEO Raingauge System, or where instruments are located at a considerable distance apart. The technology for connecting a WAN is discussed in Section 3.4.

3.4 Base Station and Wide Area Network

A base station is the main datalogger, which consists of a small computer and an external communication modem. It includes a micro-processor or industrial-type computer with a random access memory that can be programmed to assemble the captured data from various sensor nodes into a single file and transmit it to the remote data server at the data centre. The external communication modem usually adopts the mobile telemetry services for establishing a WAN between the base station and the remote data server. Once a WAN is established, the data are transferred in packets between the base station and the remote data server using the file transfer protocol (ftp). Apart from forwarding the captured data to the remote data server, the data are also stored in the memory module. This is to serve as a back-up for the transmitted data, in case the communication is disrupted.

The WAN can be established using either mobile services or land-based datalines. In urban sites where land-based datalines are readily available and easily installed and can be suitably protected, this option is preferred, as the operating cost for land-based datalines would be less than that for mobile services. However, good protection to the land-based

Table of Contents
Table of Contents
Table of Contents
Table of Contents

dataline is essential in order to ensure the reliability of data transmission. Strout et al (2008) discussed the shortcomings of using a cabled network, which include the possible failure of data transmission due to lightning events. Similar problems were also reported in the some of the GEO projects.

There are a number of mobile telemetry services offered by the local telephone companies, including GSM (Global System for Mobile communications), GPRS (General Packet Radio Services), CDMA (Code Divided Multiple Access), and HSPA (High Speed Packets Access). These mobile service technologies are suitable for sites where it would be difficult or expensive to install and protect the land-based datalines, which is typically the case where slope instrumentation is to be implemented. However, the coverage of the mobile services in remote areas is also an important consideration as regards their suitability. A poor coverage may lead to intermittent data transmission, which is highly undesirable.

GSM and GPRS represent the earlier mobile communication standards, and their data transmission rate is comparatively limited in terms of modern standards, such as CDMA and HSPA. GSM usually joins the WAN by means of a circuit-switched dial-up network. The maximum data throughput is usually 56 kbps, but it can be increased up to 256 kbps with the use of suitable data compression technology. However, circuit-switch network would require the establishment of a point-to-point route (similar to a voice call) before it is able to transmit the data. The availability of data transmission using GSM could be severely affected when the services are overloaded with large volumes of simultaneous voice calls. Alternatively, the transmission can be configured using the Short Message Services (SMS) function of the GSM to forward the data to a remote server. However, the size of an SMS is fairly limited (with 70 characters in ASCII format), and the operating cost of a data transmission system using SMS can be high, especially for instruments with a high frequency of data capture.

GPRS is the mobile communication service that overlays on the existing GSM network. It is a packet-switched network which has the advantage that it can be set as being "Always On". Unlike circuit-switched networks, a packet-switched network does not require a dedicated route along the telecommunication networks. All packet-switched traffic comes in bursts with a variable bit rate and resources are assigned on an as-needed, first-come first-served basis. Theoretically, GPRS can support a data transfer rate of up to 171 kbps. GPRS bandwidth is operated on a shared-use basis and therefore, the actual transmission rate depends on the number of multi-slots used, the time slot setting in the GPRS communication module, the number of online users, traffic volume and the applications in use. The actual data transfer rate is normally about 40 to 50 kbps. One of the key advantages of using GPRS services is that the cost is relatively affordable nowadays and that the local telephone companies usually offer a flat rate for unlimited data transmission.

Local telephone companies providing 3G services usually allow a transmission speed of up to 384 kbps for outdoor stations. HSPA is an enhancement to the existing 3G network that can increase the data transmission rate to a maximum of 14.4 Mbps for data download. The transmission rate allowed in the upload link is more relevant to the design of a real-time data transmission system. Currently, mobile companies limit the data transmission rate to 2 Mbps, which should be adequate for most scenarios. Unlike the CDMA mobile services, HSPA operates under a time sharing framework, similar to GPRS, amongst all users at the same access point. The maximum data throughput will therefore also depend on the number

Table of Contents
Table of Contents
Table of Contents
Table of Contents

of concurrent active users at the access point. CDMA is a mobile communication technology that utilizes the spread spectrum multiple access technique. CDMA is the dominant network standard in North America and parts of Asia, such as China, Japan and Korea. The data transmission rate of CDMA is about 2 Mbps, with the actual rate closer to about 300 kbps to 700 kbps. Both CMDA and HSPA are suitable for streaming videos and high definition pictures owing to their high data transmission rate. Chang et al (2006) reported the successful real-time transmission of photographs taken from site cameras in Korea by means of a CDMA communication system.

With the exception of GSM technology, current mobile telemetry services usually route the data packets through the Internet between the base station and remote data server to minimize operating costs. A virtual private network may be established to enhance the security of data transmission through the Internet. It is also feasible to establish a dedicated organization entry point for the wireless networks, or using dedicated datalines without going through the Internet, such as the datalines installed for the GEO Raingauge System. However, such option would inevitably be costly.

The power consumption of the external communication modem is usually the primary concern in the operation of a real-time slope instrumentation system. Continuous broadcasting of radio waves for the WAN would consume a substantial amount of energy. The base station would normally incorporate a rechargeable battery and solar panel. The transceiver of the external communication modem is initialized only when data communication is scheduled. Such arrangement would help to reduce the power consumption of the base station.

3.5 Information System

The information system is an important component of a real-time slope instrumentation system, because it directly interacts with the data users and provides the presentation charts and data summary to users for easy and rapid visualization of the monitored slope behaviour. For a real-time slope instrumentation system, it would be important that the system is capable of providing access to authorized users at any locations, which usually requires the provision of web-based applications. Except for the debris flow detection system, web-based interfaces have been developed for the six GEO projects to provide the users with access to the recent information via the Internet, or the intranet of CEDD.

The information system normally comprises an enterprise database for storing large volumes of data captured and a user interface for data dissemination and manipulation. Different database products have been used in the GEO projects, including Oracle, Sybase and Firebird. The enterprise database system can also provide the functionality of alerting users when pre-defined thresholds are reached. Careful consideration is needed, however, in respect of the security of the database being potentially compromised.

The implementation of web-based applications usually requires more stringent security controls, both in respect of the system design and during the implementation stage. Alert criteria are usually incorporated in the design, which should allow changes to be made by users, depending on the actual situations. For example, an alert could be targeted at a system

Table of Contents
Table of Contents
Table of Contents
Table of Contents

administrator for failures of system components, whereas an alert of imminence of real threat could be issued to decision-makers. The response action might include increasing the monitoring frequency. Such implementation would normally be designed at application levels, rather than web-based services because of security considerations. As such, it is not unusual to have an information system that incorporates different functionalities in web-based and software application platforms.

4 GEO Projects Involving Real-time Data Transmission

4.1 General

Real-time data transmission systems have been used in seven recent GEO projects (Table 1.1). Slope instrumentation systems at three of the LPM sites and the debris flow detection system were procured through ground investigation (GI) term contracts managed by the Geotechnical Projects Division of the GEO. The real-time data transmission systems were ordered as variation items. The real-time groundwater monitoring system at Po Shan Road was ordered under LPM Contract GE/2005/45. The pilot study of slope instrumentation was included as part of the LPM Contract GE/2006/10. In these six projects, the main contractors had sub-let the implementation of the real-time monitoring systems to local geotechnical instrumentation subcontractors. The subcontractors have already developed and are marketing their in-house real-time monitoring systems.

The GEO Raingauge System forms part of GEO's Landslip Warning System and has evolved over the years with service providers engaged to tailor-make the equipment and dataloggers for real-time data transmission, as well as the design of the information system. Details of the seven projects are outlined in the sections below.

4.2 Slope No. 11NW-B/C136 above Lion Rock Tunnel Road

The real-time data transmission system procured under this project was provided by FT Laboratories Ltd. using their Wireless Sensor Network (WSN).

Chan (2008) describes the registered man-made cut slope located immediately above the south portal of Lion Rock Tunnel. Figure 4.1 shows the general layout of the slope and the instrumentation. Slope 11NW-B/C136 is approximately 230 m long with a maximum of 45 m in height and a gradient of about 50 degrees. Most of the slope surface is covered with a light density of trees, except for the lowest batter which is protected by stone-pitching and shotcrete. Automatic groundwater monitoring devices were installed to monitor the groundwater levels at 30-minute intervals.

Originally, a total of 12 automatic groundwater monitoring devices were installed at boreholes Nos. PZ001 to PZ006 by the ground investigation term contractor. The automatic groundwater monitoring device is of "LevelTROLL™ 500" type, which has an 18.3 mm outer diameter and 216 mm long housing with an internal memory capable of storing about 100,000 data records. These were placed inside the standpipe piezometers (with an internal diameters of 25 mm) and were taken out for downloading the data manually at quarterly intervals. Since December 2007, a real-time data transmission system was ordered for 8

Table of Contents
Table of Contents
Table of Contents
Table of Contents

automatic groundwater monitoring devices installed in four of the boreholes (PZ001, PZ002, PZ004 and PZ005). The monitoring frequency was also changed to 15-minute intervals.

The wireless sensor network deployed by FT is based on ZigBee technology. The base station is situated at roughly the central part of the site and a tree-topology has been adopted for the sensor network (see Figure 4.1). FT collaborates with a local electronic company to develop the sensor nodes, which include the datalogger, power unit, wireless transmission unit and micro-processor. The sensor nodes have the advantage of ultra-low power consumption using ZigBee technology and they are only powered by means of AA battery cells. According to FT, the sensor nodes could run for a month before it is necessary to replace the batteries. Such devices could greatly reduce the number of visits by technical or professional staff to maintain the instrumentation system.

The base station consists of two components, viz. a sensor node and a small computer connected to an external communication modem. The sensor node is configured as the gateway sensor node in the sensor network, to which all the captured data from the other sensor nodes would be forwarded. The small computer comprises an industrial-type personal data assistant (PDA) without the display unit and associated housing. It also includes an AirCard modem for setting up a WAN (Figure 4.3). The computer will process all the captured data and compress them into a single file before transmitting to the remote data server. The AirCard modem uses mobile telemetry services for establishing the WAN with the remote data server. The base station is powered by a 12V rechargeable battery with a solar panel (Figure 4.4). FT subscribes the HSPA services of SmarTone-Vodafone for this project.

FT operates their own information system, called DeMon, which allows users to interrogate the monitoring data via the Internet (Figure 4.2). The DeMon is a common web-based platform for disseminating data captured from instrumentation projects maintained by FT. The enterprise database behind DeMon is Sybase. Session control and authentication are implemented to delineate users' rights in granting their access to data captured in any particular instrumentation projects. The presentation format in DeMon is largely integrated with "Crystal Report", which helps to generate charts and tables for presentation of the data captured. The report and data captured can also be exported in various formats, including Adobe Acrobat (.pdf), Microsoft Excel (.xls), and Microsoft Word (.rtf). DeMon uses common web-based images mapping to show sensor nodes on plan and provides some basic interaction options for users to choose and select data for presentation. However, it is not a GIS-based application that provides standard web map functionalities.

Although this specific instrumentation project does not require the setting up of alert criteria based on the monitored groundwater levels, DeMon is capable of providing alerts when measurements reach pre-defined values. The contractor monitors the battery level in the individual sensor nodes and the success rate of data transmission. The alert is executed at the enterprise database, which will be sent via SMS and/or, emails to the system maintenance parties.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

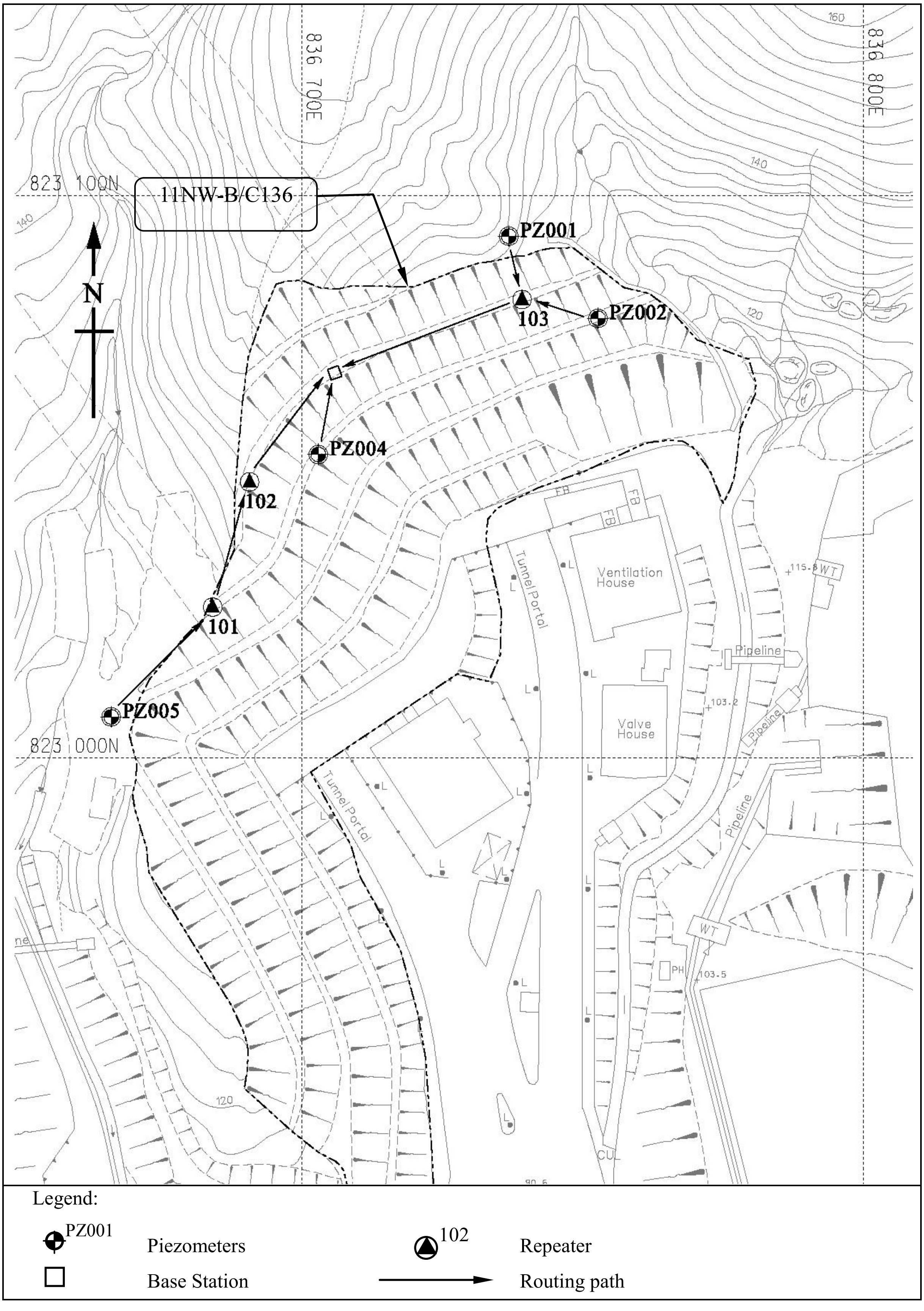


Figure 4.1 Instrumentation Installed at Slope No. 11NW-B/C136 above Lion Rock Tunnel Road

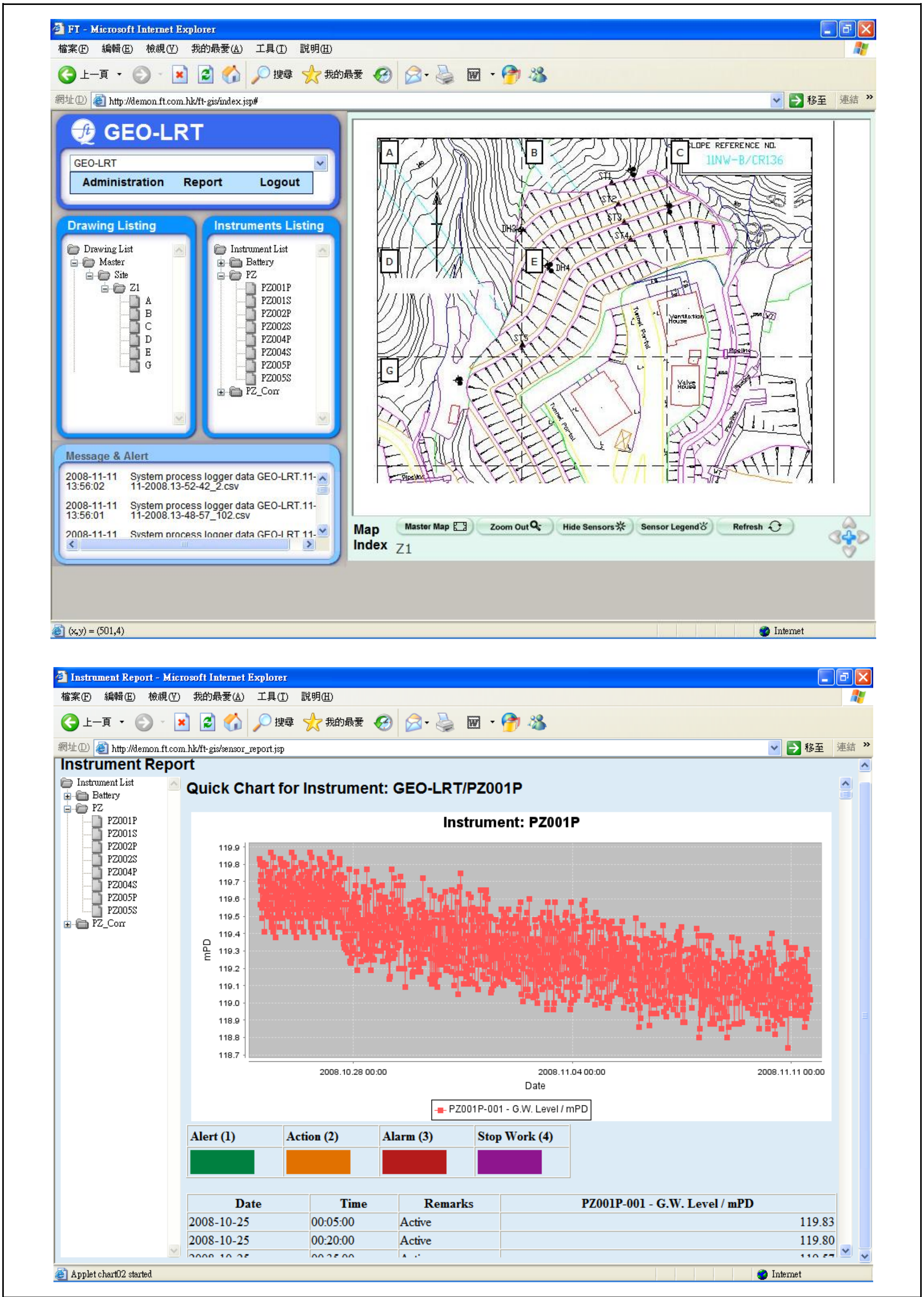


Figure 4.2 Web-based Information System Based on DeMon (Developed by FT Laboratories Ltd.)

Table of Contents

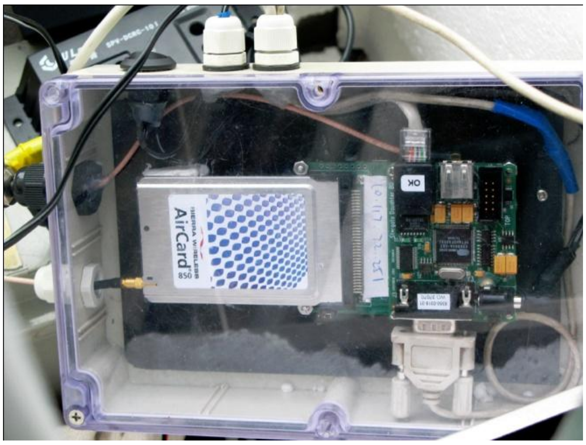


Figure 4.3 Small Computer (an Industrial Type PDA Without Display Unit) Inside the Base Station (WSN by FT Laboratories Ltd.)

Figure 4.4 Base Station with Solar Panel for Recharging Battery (WSN by FT Laboratories Ltd.)

4.3 Slope No. 15NE-B/FR31 below Shek O Road

FT is also the supplier of the WSN for the real-time monitoring system adopted on Slope No. 15NE-B/FR31.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

The slope was observed to have suffered notable deformation in November 2003, although the exact time of the movement was not known. FSWJV (2005b) reports that the maintenance stairway at the central portion of the slope was distorted, concrete steps sheared and drainage channels on the slope were severely cracked.

Routine ground movement monitoring using land-based geodetic survey was conducted by Highways Department since November 2003. The monitoring results indicated intermittent slope movement, with over 30 mm at individual markers. Slope instrumentation was installed in June 2008, which included 12 telltales, 3 sets of rod extensometers and 3 sets of in-place inclinometers. Each set of rod extensiometers (Encardio-Rite Model EDS - 70P) has three to four rods. Movements of the rods relative to the extensometer sensor installed at the top of the drillhole were measured. Each set of in-place inclinometers has seven biaxial sensors (manufactured by Applied Geomechanics Little Dipper, Model 906 V-S) installed at various depths.

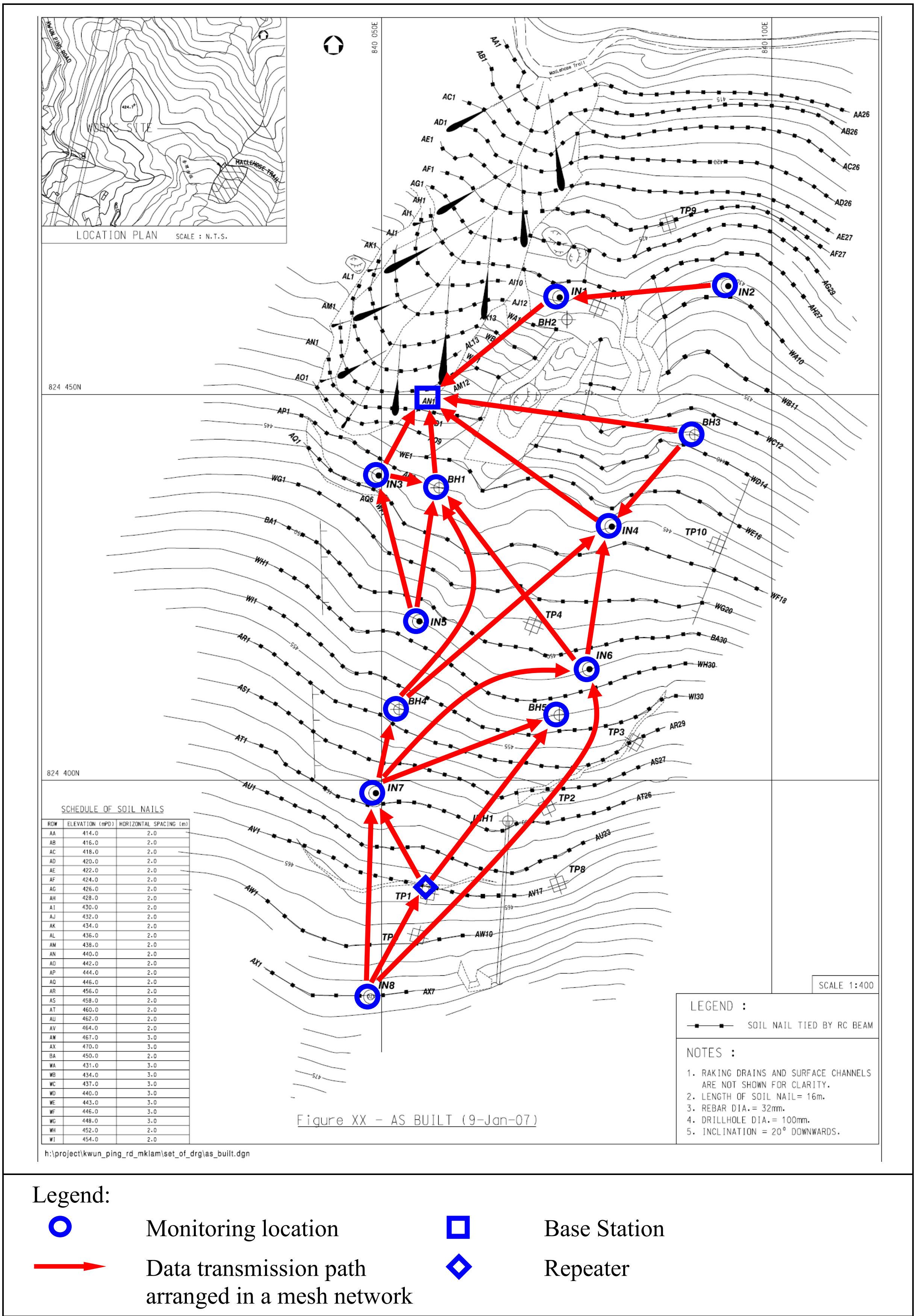
Real-time data transmission system was deployed for the in-place inclinometers and rod extensometers. The logging frequency of the movement was specified at 15-minute intervals. The data captured for this slope feature are accessible from the DeMon information system. A similar real-time monitoring system was also installed on an adjacent slope feature (No. 15NE-B/FR34) in December 2008, which comprised 12 tell-tales, 3 in-place inclinometers and 1 rod extensometer. This recent extension was not reviewed separately under the present exercise.

4.4 Distressed Hillside at Kwun Yam Shan

Fugro Geotechnical Services Limited (FGS) was engaged to deploy a real-time instrumentation system for the site. Soil nails were installed to stabilize a distressed area on the natural hillside at Kwun Yam Shan. The objective of the instrumentation was to verify the effectiveness of the slope stabilisation measures. Figure 4.5 shows the layout of the instrumentation in the distressed area. The monitoring scheme comprises 10 in-place inclinometers and 4 piezometers. The piezometers were installed in two boreholes at two depths. The monitoring frequency was set at hourly intervals but this could be adjusted to 1-minute intervals where necessary.

FGS has developed a RAdio Data Acquisition System (RADAS) as the real-time data transmission system (Figure 4.6). RADAS also adopts the ZigBee technology for its wireless sensor network. According to FGS, RADAS is capable of deploying 32 sensor nodes within a sensor network. It would be feasible to install more than one sensor network within a site to increase the total number of sensor nodes, where necessary. The wireless transmission between sensor nodes deployed in RADAS could be enhanced with an external antenna (Figure 4.7a), which can extend the maximum line-of-sight distance between sensor nodes to about 300 m. In case of obstacles between sensor nodes that might weaken the signal strength, a repeater may be added to provide an alternative network path (e.g. data transmission path from IN8 to BH5 in Figure 4.5).

Table of Contents
Table of Contents
Table of Contents
Table of Contents



ROW	ELEVATION (mPD)	HORIZONTAL SPACING (m)
AA	414.0	2.0
AB	416.0	2.0
AC	418.0	2.0
AD	420.0	2.0
AE	422.0	2.0
AF	424.0	2.0
AG	426.0	2.0
AH	428.0	2.0
AI	430.0	2.0
AJ	432.0	2.0
AK	434.0	2.0
AL	436.0	2.0
AM	438.0	2.0
AN	440.0	2.0
AO	442.0	2.0
AP	444.0	2.0
AQ	446.0	2.0
AR	456.0	2.0
AS	458.0	2.0
AT	460.0	2.0
AU	462.0	2.0
AV	464.0	2.0
AW	467.0	3.0
AX	470.0	3.0
BA	450.0	2.0
WA	431.0	3.0
WB	434.0	3.0
WC	437.0	3.0
WD	440.0	3.0
WE	443.0	3.0
WF	446.0	3.0
WG	448.0	3.0
WH	452.0	2.0
WI	454.0	2.0

Figure 4.5 Instrumentation Installed at Distressed Hillside at Kwun Yam Shan

Table of Contents
Table of Contents
Table of Contents
Table of Contents

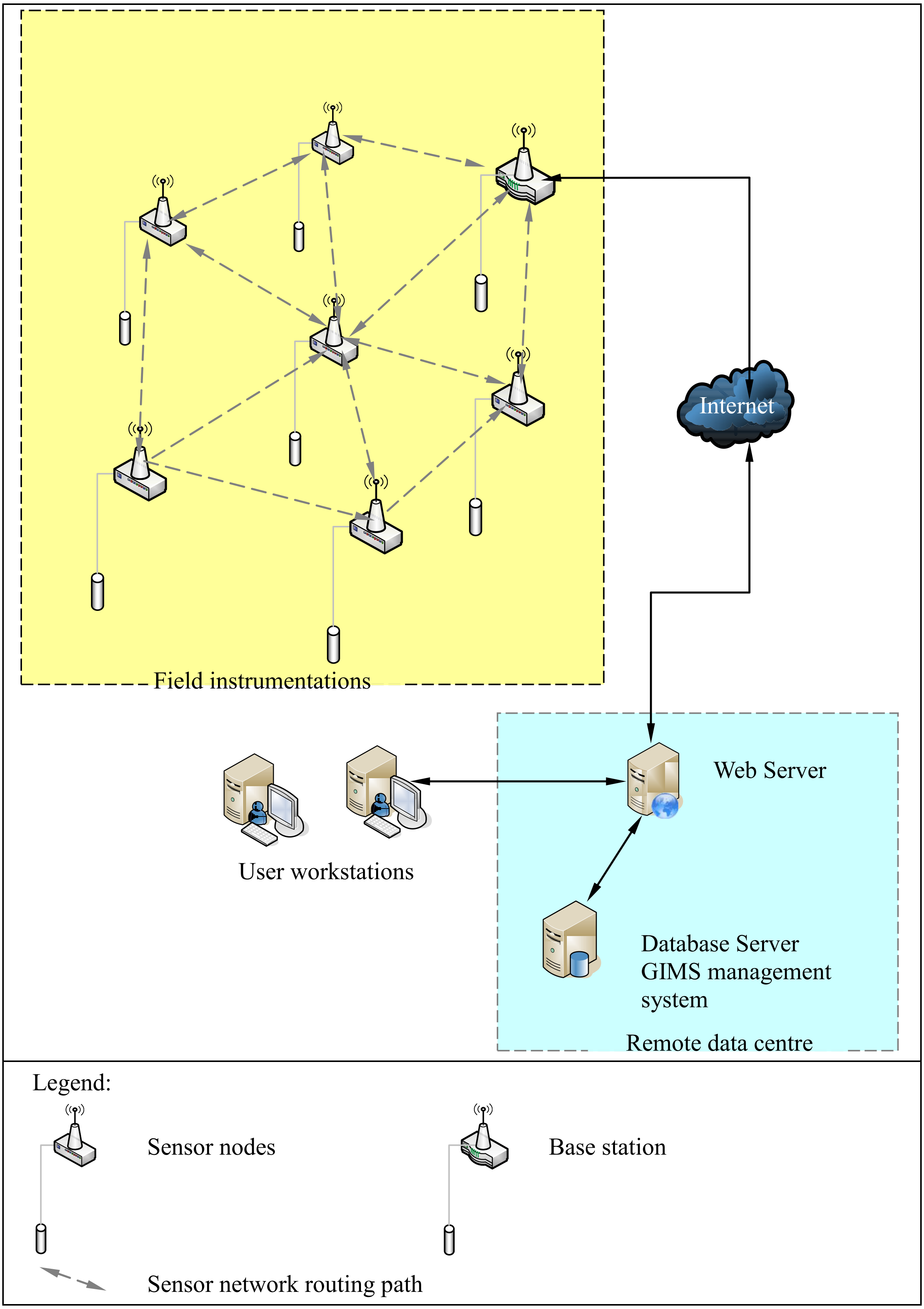


Figure 4.6 Schematic Diagram of RAdio Data Acquisition System by Fugro Geotechnical Services Limited

Table of Contents
Table of Contents
Table of Contents
Table of Contents

The base station in RADAS is composed of a small computer that processes the data files received from individual sensor nodes. The small computer is of industrial-type that operates on LINUX. FGS uses a GPRS modem to establish a WAN between the remote data server and base station. Data transmission between the two is enabled by using the file transfer protocol (ftp). Similar to the DeMon system, the data are compressed to a single file before it is transmitted to the remote data database server at hourly intervals. FGS uses GPRS services offered by SmarTone-Vodafone.

Unlike FT's system, FGS uses a larger rechargeable battery (i.e. a car battery) to power the individual sensor nodes (Figure 4.7b). With this, the maintenance visits for replacing the battery were reduced to once every 3 to 4 months. Similar to FT's system, the rechargeable battery in the base station is connected to a solar panel. The positioning of the base station at the Kwun Yam Shan site had taken into consideration the availability of sunlight for recharging the battery (Figure 4.7c). Figure 4.7d shows the hardware of the datalogger and the base station of RADAS.

FGS has developed the Geotechnical Instrumentation Monitoring System (GIMS) to allow users to interrogate the monitoring data captured from sites (Figure 4.8). The enterprise database behind the GIMS is Oracle 9i and a web-based interface is provided as the front-end for users to access the data via the Internet. It is also a common platform that disseminates monitoring data for all real-time instrumentation projects provided by FGS. The monitoring data can be viewed in tabulated and graphical format and be downloaded in Microsoft Excel format (.xls) for further analyses by the users.

4.5 Landslide Preventive Works at the Hillside above Po Shan Road, Mid-levels

The RADAS of FGS was deployed to capture real-time data on groundwater levels at the hillside above Po Shan Road since February 2007. Solomon et al (2008) describe the background and technical details of the instrumentation schemes under the project. One of the primary objectives of the project is to control the groundwater levels to within a desired range. The geotechnical works include the construction of two 3.5 m diameter drainage adits (175 m and 260 m in length respectively) and the installation of sub-vertical drains at the hillside above Po Shan Road. 52 piezometers were installed at the site and a real-time instrumentation system was established. Figure 4.9 shows the instruments installed on site and the network topology. The frequency of data capture was set at 5-minute intervals. A highest and lowest groundwater level at each piezometer was specified as the alert levels triggering follow-up actions, e.g. temporary closure of drains when the groundwater level is too low. The captured data are accessible from GIMS.

4.6 GEO Raingauge System

The GEO Raingauge System has been developed since 1984, with continuous improvement and enhancement over the years. The Raingauge System monitors the rainfall over Hong Kong, which provides essential information for predicting the number of landslides during severe rainstorm events and for operating the Landslip Warning System.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

(a) Sensor node with extended antenna to improve data transmission range

(b) Datalogger and battery inside the protective casing

(c) Solar panel recharging the battery in the base station. Two antennae are installed for LAN and WAN

(d) Components inside a base station

Figure 4.7 Components of RAdio Data Acquisition System (RADAS) by Fugro Geotechnical Services Limited

Table of Contents
Table of Contents
Table of Contents
Table of Contents

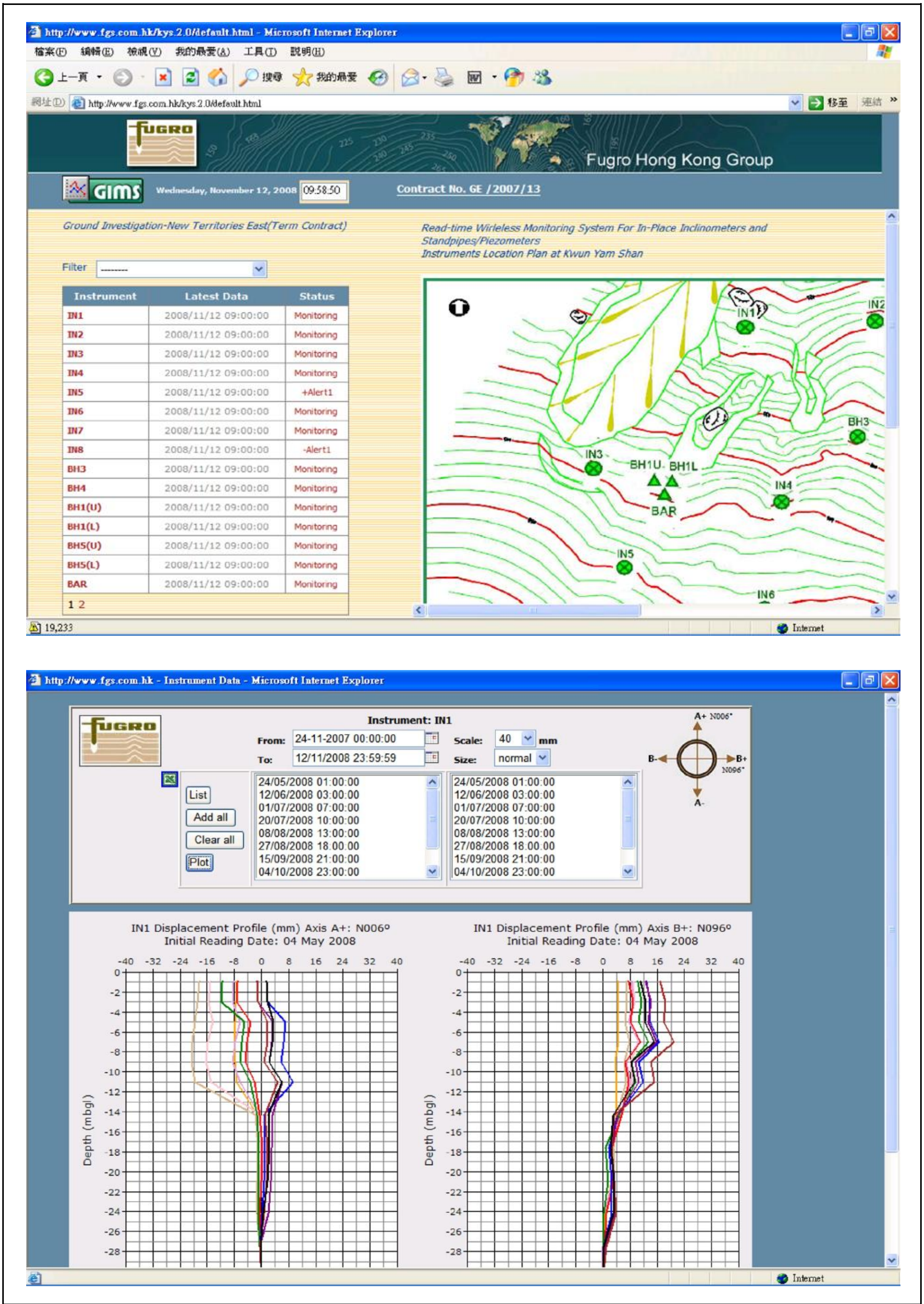
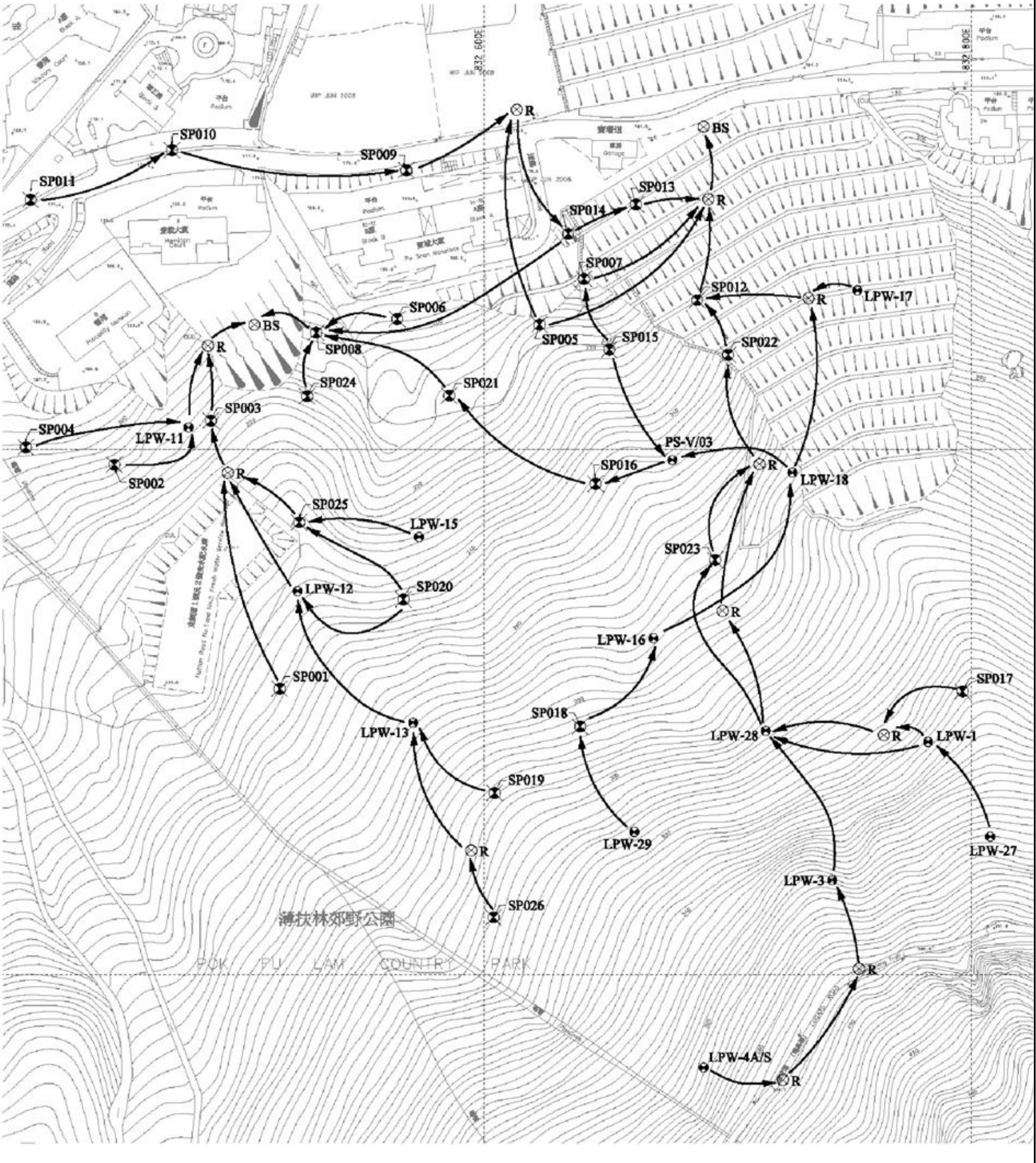


Figure 4.8 Geotechnical Instrumentation Monitoring System (GIMS) by Fugro Geotechnical Services Limited

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Legend:

⊗R	Repeater	⊗BS	Base station
SP02	Instruments	⟶	Routing path

Figure 4.9 Instrumentation Installed at the Hillsides above Po Shan Road (Based on ZigBee Technology)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

At present, the GEO Raingauge System comprises 110 automatic raingauge stations, 86 of which are managed by the GEO. Each automatic raingauge station can be considered as a base station in the instrumentation system, in which data are collected and sent directly to the remote data servers at the GEO. The system utilizes two means of transmission, including land-based datalines and mobile telemetry services, for establishing the WAN to connect the raingauge station and remote data servers. The land-based datalines have been used since 1984, but these are gradually replaced by the mobile telemetry services based on GPRS currently provided by CSL Limited. There are currently 15 automatic raingauge stations that still utilize land-based datalines.

Each automatic raingauge system comprises three components including the instrument (i.e. a tipping bucket), a datalogger equipped with a GPRS modem and a power unit. Electronic companies were engaged to manufacture the datalogger for recording the rainfall data. The power unit includes a 20 watt solar panel charging two 12V, 12Ah rechargeable batteries. The set up allows adequate power supply to operate the datalogger and GPRS data transmission even without sunlight for 15 to 20 days. The system is able to monitor the power voltage remotely and maintenance action would be initiated as and when necessary.

The automatic raingauge stations collect rainfall data at 5-minute intervals. Apart from transmitting data to the remote data server via WAN, the data are also stored in the memory module of the datalogger. The memory module is capable of storing up to 31 days of rainfall data (i.e. 8928 entries). The system includes subroutines that allow the servers to scan through the data received in the past hour and give instructions to reload any missing data. For security considerations, the data captured through GPRS are initially received in external data servers operated by the CSL Limited. The data are then consolidated into a single file before forwarding to GEO data servers. Datalines have been installed to connect the servers at GEO and CSL data centers.

For the land-based dataline connection, the WAN is established by dial-up networking using telephone modem to create a circuit-switch network between the GEO data servers and automatic raingauge stations. There are two multiplexing modem units in the GEO, each of which will call the automatic raingauge stations in sequence to collect the rainfall data. As the data is collected at 5-minute intervals, the schedule of calling all 15 automatic raingauge stations within the interval is fairly tight. It should be noted that the land-based datalines do not go through the Internet.

Improvements to the GEO Raingauge System had been made at different times, with several additions to the back-end system for storing and manipulating the data. The system can be effectively divided into two modules. One module runs on software applications developed on Microsoft Visual Basic. This software architecture requires the program to be installed on users' workstations and connected to a separate network domain. As such, their availability is limited. The other module, which is developed in recent years, is a web-based application based on Microsoft ASP.NET. The web-based application is accessible from workstations connected to the Civil Engineering and Development Department (CEDD) internal network. An enhancement project is currently in progress to allow authorized users to access the web-based GEO Raingauge System via the Internet.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

The enterprise database system for the GEO Raingauge System is Oracle 10g. The web-based user interface provides the graphical and tabulated rainfall data. Alert criteria have been set to alert the relevant officers of the time when the landslip warning level is being approached or has been reached.

4.7 Instrumentation Work under Contract No. GE/2006/10

As part of the mitigation measures under Contract No. GE/2006/10, the GEO has installed a real-time instrumentation system on hillside area at four sites. The main contractor sub-let the instrumentation work to Sol-Data Asia Limited (Sol-Data). Lau et al (2008) describe the background and technical details of the instrumentation schemes under the project. Instruments installed at the hillsides at Pa Mei, Tung Chung East, Tsing Shan and Ching Cheung Road and the details of the monitoring (including instrumentation set-up, frequency of data capture, alert criteria, planned actions, etc.) are given in Table 1.2. Sol-Data was responsible for installing the instruments, except for two GPS monitoring systems at Tsing Shan Foothill and the Tension, Rotation and Settlement (TRS) Sensors at Pa Mei. The two GPS systems were installed by specialist contractors, Leica System (1 local reference station and 3 monitoring stations) and the Hong Kong Polytechnic University (a multi-antenna system comprising 1 local reference station and 5 monitoring stations) respectively, whereas the TRS stations were installed by Professor K.T. Chang of Kumoh National Institute of Technology, South Korea. Details of the TRS sensors and the methodology for data interpretation are given in Chang et al (2006) and Chang & Ho (2008).

The instruments at the above sites were grouped into 4 to 6 clusters, each of which is equipped with a datalogger and a wireless communication modem. The instruments are connected with the datalogger by means of land cables. According to the consultants managing the project, the maximum lengths of land cables are limited to less than 10 m, in order to reduce the likelihood of lightning strike, as required by the Particular Specifications. All the base stations are grounded using 1 m long copper earthing rods, with earth shields from all electrical devices (i.e. dataloggers, modems, etc.) connected to the grounding rod using 4 mm diameter earthing cables. In addition, all land cables connecting the sensors to the base stations are housed within protective conduits and buried at least 100 mm beneath the ground surface in order to safeguard the equipment against lightning. Lightning arrestors are also installed adjacent to the GPS monitoring stations at Tsing Shan Foothill.

The external communication modem in each base station uses GPRS to establish the WAN between the datalogger and the remote data servers. Such arrangement might not necessarily be the most cost-effective solution in terms of long-term operating costs for the four sites. The subscription for the mobile telemetry services could be reduced if a local area network (i.e. sensor network) was to be set up instead.

Sol-Data has developed the Geoscope System as the application and presentation tiers for their real-time data monitoring system. The contractor has deployed a Contractor Database System (CDS) based on the Geoscope System for users to access the data initially, so as to meet the project programme in delivering services under the contract. The enterprise database of the CDS is based on Firebird. One of the advantages of using Firebird is that it is a free software. Users, including staff from the GEO and consultants, can access the captured data via the Geoscope Web module. Although this is marketed as a web service,

Table of Contents
Table of Contents
Table of Contents
Table of Contents

additional plug-in's need to be installed to integrate the Geoscope functionality in Internet Explorer. The data captured by the GPS monitoring stations are not incorporated in the Geoscope Web System and a separate data transmission system is provided by Leica and the HKPU.

The contractor has also deployed the Employer Database System (EDS) in GEO. The EDS uses Oracle 11g as the enterprise database system for storing and manipulating the data. The application and presentation tier of the information system behind the EDS continues to be based on the Geoscope system. The Geoscope system is a suite of tailor-made applications developed using Borland's Delphi. A total of 30 Geoscope licenses had been included in the contract for giving concurrent access to the system.

The Geoscope has 8 independent modules for different functionalities, including data acquisition, alarm system, database, data visualization, data export, data security and visualization using web services. The alert system could send an SMS or an email to designated personnel, in case two consecutive monitored data values have exceeded a specific level. Figure 4.10 depicts the user interface of the Geoscope System.

4.8 Debris Flow Detection System at Tung Chung

In July 2008, Fugro Geotechnical Services Limited (FGS) was engaged by the GEO to install a debris flow detection system at a debris flow site above Yu Tung Road, Tung Chung, following the debris flow triggered by the severe rainstorms in June 2008. The system was composed of steel wires stretching across the debris trail (Figure 4.11). The steel wires were supported on vertical steel posts embedded into the rock mass. When debris hits the detection system with sufficient energy, the tilt sensors mounted on the vertical posts would trigger the system to send a warning text message to pre-set mobile phone numbers via SMS. The SMS message will be sent out when tilting of the vertical posts exceeds 15°. As a health check of the system, a testing SMS will be sent out each day to indicate continuous operation of the system.

The debris flow detection system was relocated to a stream course near Tung Chung Eastern Change, Lantau in January 2009, following the commencement of the remedial works on the hillsides. Figure 4.13 shows the present locations of the system. In addition to the tilt sensors mounted on the vertical steel posts, vibration sensors mounted vertically on selected rock surface were added to the detection system (Figure 4.12). Each vibration sensor consists of 3 internal geophones that monitor the ground vibration velocities generated in the longitudinal, transverse and vertical directions by the debris in motion. The vibration sensors generate a signal in unit of voltage that is proportional to the resultant kinetic energy as measured by the three geophones. The threshold value of voltage signal (i.e. 3 volts) triggering an alert SMS message was determined by hammer strikes near the vibration sensors on site that simulated the vibrations generated by a debris flow.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

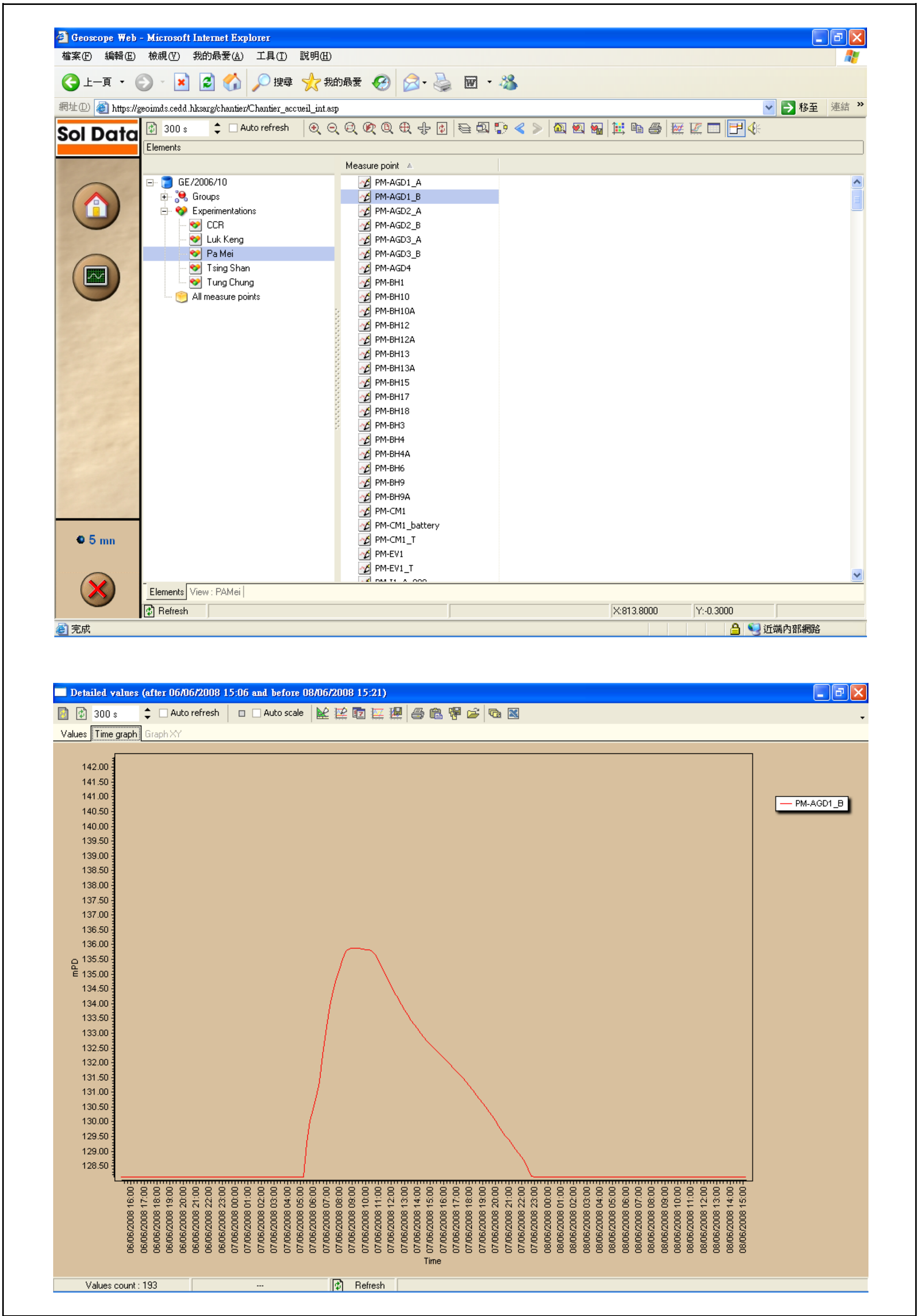


Figure 4.10 User Interface of the Geoscope System

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Figure 4.11 Tilt Sensor in Debris Flow Detection System (at Yu Tung Road Debris Trail)

Figure 4.12 Vibration Sensor in Debris Flow Detection System (at Tung Chung Eastern Change, Lantau)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

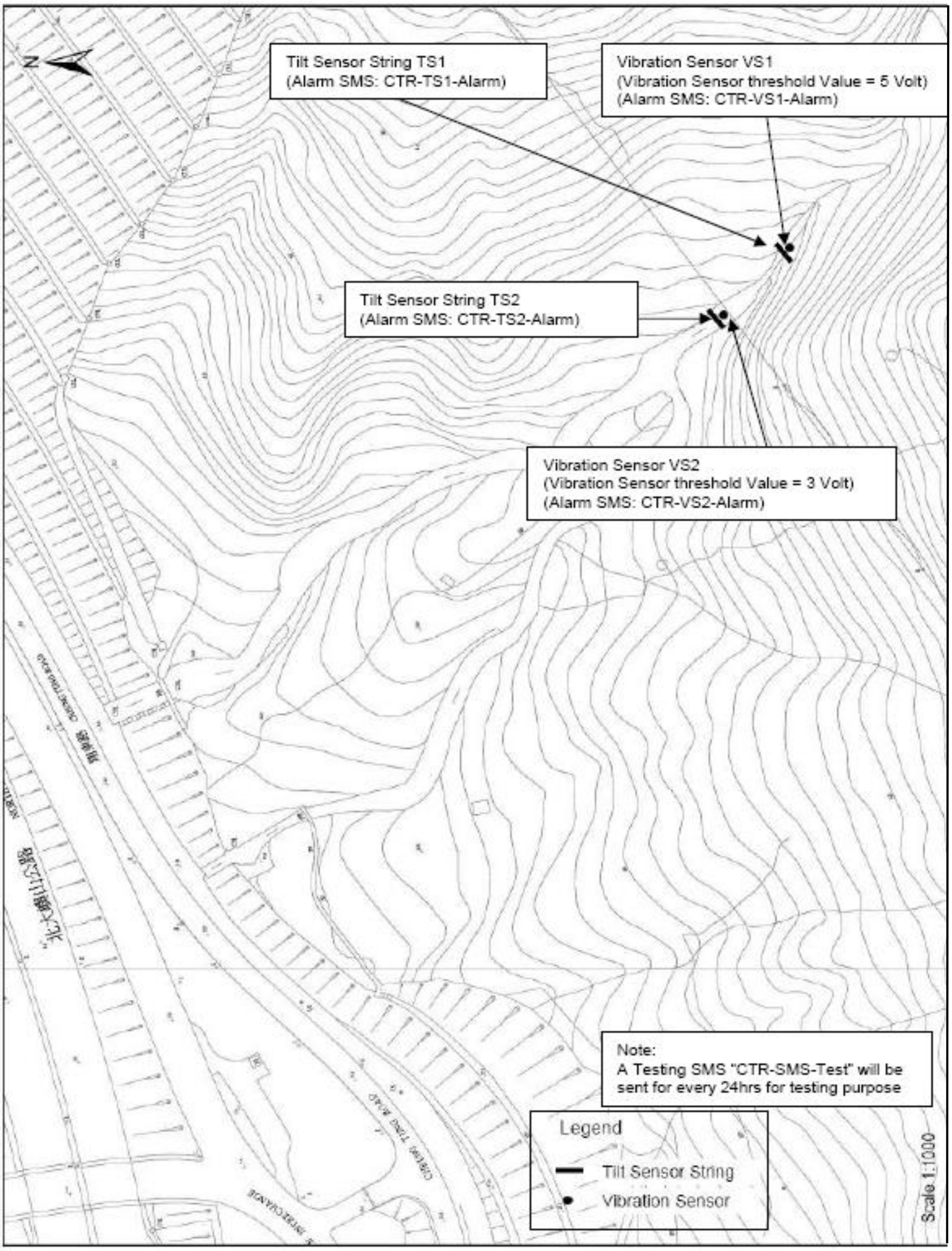


Figure 4.13 Debris Flow Detection System at Tung Chung

Table of Contents
Table of Contents
Table of Contents
Table of Contents

5 Performance of Real-time Data Transmission Systems

The performance of a real-time data transmission system may be measured by the availability of the captured data to the end users within a reasonable or the specified timeframe, such that appropriate alerts or follow-up actions could be initiated. However, it should be noted that the performance of a real-time monitoring system would depend on many factors, including the reliability of instruments, successful data acquisition of the dataloggers, coverage of wireless mobile signals or stability of cabled networks, effectiveness of the information system deployed at the remote data centre, etc. Of the seven GEO projects where real-time data transmission systems have been deployed, their performance to date has generally been satisfactory. In particular, the systems managed to provide real-time data during severe rainstorms, including those in June 2008.

However, no systems are foolproof and there have been some occasions when data were not received in real-time. For the instrumentation systems deployed in the four LPM sites under Contract No. GE/2006/10, the instrumentations were designed to provide real-time alerts to users although the alert mechanism is not activated yet. The DeMon and Geoscope Systems record the time stamps when the measurements are taken, but these systems do not register the time at which the data were forwarded to and processed by the information system. It is therefore not possible to assess the delay between the time of capturing the data and the time that the data are accessible to the users. Although RADAS records both time stamps, it is understood from FGS that the clocks at the base station and the servers are not synchronized. The assessment of the performance of the above real-time instrumentation systems can only be based on periodic observations made by the authors between October 2008 and April 2009, together with discussions with the users of the systems. For the instrumentation project under GE/2006/10, the consultant has submitted reports on instrumentation techniques implemented at the 4 sites in September 2008. Therefore, the performance of the Geoscope System is summarized based on a review of the reports prepared by the consultant.

When the GEO Raingauge System was upgraded in 2005 to utilize mobile telemetry services, the system had been re-designed such that it now records the time stamps when the automatic raingauge takes the measurements and when the data are transmitted to the servers. This enables an assessment of the reliability of the data transmission via mobile telemetry services based on GPRS.

Power consumption is one of the key considerations in operating a real-time data transmission system. Failure in the power supply was the reason behind some of the problems encountered in selected projects with real-time data transmission systems. Two events occurred with the RADAS (at Kwun Yam Shan site) and DeMon (at Lion Rock Tunnel Road site) systems during the observation period, where the real-time data were missing. The problems were found to have been caused by the draining of the battery power. In fact, the readings in previous transmissions had indicated signs of deterioration in the voltage. Subsequent discussions with the contractors confirmed that the problem was related to the power supply for the base station. Data transmission resumed normal after the battery was replaced. It is understood that the contractors were notified by SMS within an hour of the draining of the battery. However, it took a few days for the contractor to arrange technical personnel to replace the drained batteries. In the case of the Kwun Yam Shan site, the contractor enhanced the system by installing an additional set of solar panel and rechargeable

Table of Contents
Table of Contents
Table of Contents
Table of Contents

battery as a back-up electric supply for the base station.

The consultant responsible for the instrumentation project under Contract No. GE/2006/10 has monitored the performance of the real-time data transmission system and prepared reports on the instrumentation techniques implemented. The consultants were generally satisfied with the response rate of the contractor in initiating maintenance actions in rectifying problems identified. There were some periods of missing data with the system, which were due to the poor performance of the monitoring sensors and bugs in the program respectively. Several erroneous readings were also obtained in several inclinometers, in which the readings indicated a movement of about ±8,000 mm. The consultants attributed the erroneous data to the effects of lightning. The influence of lightning on real-time data transmission systems was also reported in previous trials conducted by GEO (Chan & Wong, 2001) and highlighted by Strout et al (2008). Typical lightning protection measures include direct grounding, gas discharge tube and transient absorber diode (Choquet, 1995).

The reliability of the real-time data transmission system in the GEO Raingauge System is well proven, as it has been deployed for over 4 years in providing essential data for the operation of the Landslip Warning System. Based on the data transmitted through GPRS between April 2008 and December 2008, more than 98% of data captured were received and processed within 30 minutes from the time that the measurements were taken at the raingauges. On the other hand, the success rate of data transmission using land-based data line could not be established, as the time stamps for receiving the data in the remote server are not recorded in the computer program. The effect of lightning on those raingauges using land-based data line was minimal, as there was no known incident where data were missing or equipment damaged due to lightning. The raingauges using land-based data lines are located on the roof of buildings. The lightning protection system of the building would probably provide sufficient protection to those raingauges.

The Debris Flow Detection System at Tung Chung was triggered on 5 March 2009 where an SMS message was issued to the designated personnel. FGS inspected the site on the following day and noted that the alarm was not triggered by debris hitting the detection system. The alarm was issued due to malfunctioning of the electric circuit board, as the moisture condensed on the circuit board apparently led to intermittent fluctuations of the voltage in the vibration sensors. The contractor implemented remedial measures to minimise the condensation of moisture inside the housing of the equipment. These measures included cleaning of the circuit board, placing extra desiccant dryer, and applying silicon grease around the door hinges and hosing inlet to the equipment cabinet.

6 Discussion

A number of different real-time instrumentation systems have been deployed in various GEO projects in recent years. Each of the arrangements has its own advantages and disadvantages. The services procured under the ground investigation term contracts can be considered as a 'one-stop shop', where the contractor provides the instruments as well as the corresponding information system for users to interrogate the monitored data. Input by the data users in the setting up of the system was kept to a minimum in these cases.

Under such contractual arrangement, the information system (e.g. DeMon and RADAS)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

is deployed at the contractor's site office or data centre. This avoids the potential problems of security if the system were to be deployed in CEDD’s internal network. However, this arrangement would not allow web-based information systems to have much interaction with the sensor nodes in the field. The web-based system would not normally be designed to allow instructions to be sent to the sensor nodes via the web-based interface on the Internet. The maintenance of the systems would also depend very much on the services provided by the contractors. Thus, the GEO would have only limited input and a restricted role in maintaining and improving the performance of the real-time monitoring systems. This would not be desirable in cases where the monitoring data are critical on a real-time basis for taking follow-up actions, e.g. the operation of the Landslip Warning System based on, inter alia, the raingauge system. In addition, the use of a shared platform amongst other commercial users might not be preferable, particularly where potentially sensitive information is involved in the processing.

The GEO’s ground investigation term contracts are usually procured for a period of two years. There may be occasions where the subcontractors responsible for providing the real-time instrumentation systems may need to be changed, as the new main contractor may select another subcontractor to provide the real-time instrumentation system. This took place in the case of the Kwun Yam Shan project, where the instrumentation subcontractor had to be switched from Sol-Data to FGS. The subcontractors had to arrange a gradual replacement of the real-time instrumentation system to facilitate continuation of the field measurements. Such arrangement calls for good logistic support from both subcontractors and this may induce an additional element of risk in respect of possible loss of some monitoring data. In addition, even when the same subcontractor is appointed to continue the monitoring work, it could take some time to have the works order issued under the new term contract and the real-time monitoring service could be disrupted until the works order is issued. This was the case with the monitoring of the slope feature at Shek O Road whereby the DeMon system was suspended for three weeks when the new ground investigation term contract commenced in April 2009.

Datalogggers in local systems (e.g. RADAS and DeMON) using Zigbee technology are not designed to take frequency measurements from vibrating wire sensors. However, this could be done by incorporating a suitable module to convert the frequency measurements to digital signals. Kim et al (2007) reported the use of vibrating wire type sensors using Zigbee wireless technology to monitor the displacement and stresses developed during tunnel construction in Korea.

It is understood that particular specifications for procuring the services of providing a real-time groundwater monitoring system are being prepared by the Geotechnical Projects Division based on previous experience in the use of different real-time monitoring systems. It is intended that the real-time monitoring services would continue to be ordered as variation items under the existing ground investigation terms contracts.

The response rate in taking suitable remedial maintenance actions to resolve system problems is also an important consideration when procuring a ‘one-stop shop’ service from the contractors, particularly for those systems that are to be used as warning systems that would call for immediate actions. The operation of such system requires a ‘7 x 24’ support team that is ready to work readily even under extreme weather conditions, assuming access is not an issue.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

The instrumentation system currently procured under Contract No. GE/2006/10 is to be delivered to the GEO upon completion of the project. The arrangement requires the installation of equipment and network devices in the CEDD internal network, together with the setting up of an Internet gateway. Unless further maintenance services are procured from the contractors, the maintenance and operation of the instrumentation system would be taken up by the system owner, i.e. GEO. The Geoscope System provided by the contractor is a compiled program and the maintenance of such a system without the source code would be a considerable challenge. Geoscope Web is an application plug-in to the Internet Explorer and the installation of this plug-in in workstations is limited by the number of licenses procured under the contract. In addition, it will be necessary to deploy competent personnel to carry out routine maintenance of the system, such as changing the batteries, regular calibration of the sensor nodes and base stations, as well as replacement of malfunctioned devices.

The real-time data transmission system deployed under Contract No. GE/2006/10 did not consolidate the data recorded in individual sensors before forwarding the data to the remote server. Such arrangement would unavoidably involve a higher recurrent cost for procuring mobile telemetry services for data transmission system. Where site conditions permit, it would be preferable to select a system with a local area network, so that the number and location of base stations could be optimized and are located at places where stronger telemetry signals are available or where exposure to sunlight is larger. This would reduce the risk of data loss and the routine maintenance works required for replacing the batteries.

The GEO Raingauge System was developed essentially in-house with the assistance of computer specialist through services. One of the advantages of developing the real-time monitoring system in-house is that there will be a greater control over the performance and reliability of the system. In addition, any system enhancement can be made more easily by the in-house team on a need basis. However, it would take a longer time and deployment of resources in GEO to develop and maintain the system as compared to procuring the services from commercial organizations.

Apart from GEO's experience in using real-time monitoring systems, the Survey Division of CEDD also conducted a trial use of Global Positioning System (GPS) and fibre optics sensors to monitor the movement of a seawall at Tseung Kwan O Area 137 (Li, 2008). The system is equipped with GPRS modems for transmitting the monitored data to the server in the Survey Division. The base station of the GPS Monitoring System is composed of a GPS receiver, DC batteries and a GPRS modem in a protective cabinet. The system of fibre optics sensors includes Fibre Bragg Grating (FBG) sensors, temperature sensors and camera. Data are transmitted to the server in the Survey Division via a GPRS modem with the GPRS service provided by China Mobile Peoples Telephone Company (now traded as China Mobile (HK) Co. Ltd). The Survey Division's experience indicated that real-time data transmission by GPRS suffered breaks of data transmission due to temporary failures of the GRPS network. The high temperature inside the equipment cabinet might also have aggravated the instability problem of the data transmission system.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

7 Key Observations and Suggestions on Improvement Measures

Based on a review of the experience in the use of different real-time data transmission systems under various GEO projects, together with the recent advances in wireless technology and mobile telemetry services that are available in Hong Kong, the following suggestions are made with a view to further enhancing GEO's capability in implementing real-time slope monitoring:

(a) There is limited experience in the use of the various real-time data transmission systems given a relatively short time span of one to two years, except for the GEO Raingauge System. While the current review indicates that the systems are generally satisfactory in terms of their capability of providing real-time monitoring data, it would be prudent to continue to monitor the performance of the various data transmission systems for a longer period.

(b) Where the site conditions and site settings permit, a local wireless network (e.g. a sensor network) should preferably be deployed to connect the individual sensor nodes in the instrumentation network, before the monitoring data are consolidated and transmitted to a remote data server via the wide area network. The ZigBee technology for the sensor network has worked well, with a low maintenance costs and automatic routing capability.

(c) The application of a local wireless network should consider the data traffic required for the types of instruments deployed. Where data transmission requires high data volume throughput (e.g. video capture in the field), individual sensor nodes should preferably be configured as base stations with CDMA and HSPA mobile telemetry. Wireless sensor nodes based on Zigbee technology is not suitable in this case because of its slow data throughput.

(d) Power consumption is a key consideration when implementing a wireless sensor network and considering data transmission offsite. A back-up power supply for the base station should be provided to avoid disruption of the system and data loss in the event of a sudden draining of the battery power.

(e) Land-based cables should be minimised in the field as far as practicable and, where used, they should be protected from lightning (e.g. buried underground). Sensor nodes and base station should be guarded against lightning by suitable protective measures, such as installation of lightning arrestors. The information system should also be capable of filtering irrational data spikes.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

(f) Consideration should be given by the GEO to develop an instrumentation platform for integrating all the data captured under different GEO's instrumentation projects. Such a platform could be used to interface with different 'commercial' systems provided by various companies offering real-time instrumentation monitoring services for future applications. The use of XML data services has the advantage that it is relatively independent of the web-based technologies (e.g. PHP, ASP.NET, Java) adopted in different 'commercial' systems and the data format. Data transmitted in XML format are tagged with fieldname identifications that would simplify the program codes for reading XML data from different sources. Any alert messages used for advanced warning purposes could also be generated on the instrumentation platform instead of through the 'commercial' systems. An instrumentation platform developed and managed by GEO in-house staff would allow greater flexibility in enhancing the functionality on a need basis. In addition, a dedicated maintenance team could be assigned to ensure the reliability of the system.

(g) The procurement of real-time monitoring systems could be considered as a regular item under the GI term contract. Particular attention shall be given to ensuring continuity of data collection during the transition period of successive GI term contracts. Appropriate specifications for the provision of real-time data transmission services should be prepared based on the experience gained to date as presented in this review (e.g. a tolerable time delay in data transmission from sensor node to the remote server, etc.). Consideration should also be given to requiring the contractors responsible for providing field instrumentation to include the provision of data services based on Extensible Markup Language (XML) via the Internet, which will support the development of an instrumentation platform as mentioned in item (f) above.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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Table of Contents Table of Contents Table of Contents Table of Contents

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

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