New Capability and Opportunities for Using Digital Technology in Geotechnical Engineering

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Abstract: Digital technology offers an opportunity for advancing geotechnical practice and enhancing the capability and efficiency of geotechnical work. This paper describes a number of novel digital technologies, which have notable potential for geotechnical application in Hong Kong. These include digital photogrammetry, Geographic Information System (GIS), Interferometric Synthetic Aperture Radar (InSAR) and Light Detection and Ranging (LIDAR). Their principles, capability, current application and future potential are presented. These technologies have been identified by the HKIE Interest Group on Application of Innovative Technology in Geotechnical Engineering as novel techniques that warrant strategic attention.

INTRODUCTION

Significant advances have been made in digital and related novel technologies over the years. The technologies have become more readily accessible, with improved capability and reduced cost. Hong Kong is one of the parties taking the lead in applying novel technologies to geotechnical work (Wong 2001), and some of these applications are recognized as the state-of-the-art that has brought about enhanced geotechnical capability (SSTRB 2003 & 2004).

In recognition of the importance of novel technologies and their potential application, an Interest Group on Application of Innovative Technology in Geotechnical Engineering was set up by the Geotechnical Division of the Hong Kong Institution of Engineers (HKIE) in mid-2003, with members from academic institutions, Geotechnical Engineering Office (GEO), and geotechnical practitioners in Hong Kong. The Group is tasked with developing knowledge and promoting geotechnical application of innovative technologies, which would help the geotechnical profession to meet new challenges in Hong Kong and to lead the professional excellence in the region.

The Group has identified the following eight strategic subjects for examination and promulgation of their geotechnical application:

(1) construction control and technology;
(2) digital photogrammetry;
(3) Geographic Information System (GIS);
(4) Global Positioning System (GPS);
(5) instrumentation;
(6) Interferometric Synthetic Aperture Radar (InSAR);
(7) Light Detection and Ranging (LIDAR); and
(8) new geotechnical subjects, including environmental geotechnology, natural terrain landslide hazard and quantitative risk assessment.

Items (2), (3), (6) and (7) above directly involve the use of novel digital technologies. Their technological principles, capability, current applications and future potential are summarized in this paper. Item (4) above is partly related to GIS and LIDAR application, and is also described in such context in this paper. Three 'case report' papers, which supplement this theme paper, are included in the proceedings of this Seminar. These papers give a detailed account of selected application cases, which include ground movement detection using InSAR (Ding et al. 2004a), mobile GIS mapping (Ng et al. 2004) and boulder identification using image analysis techniques (Shi et al. 2004).

DIGITAL PHOTOGRAMMETRY

Hong Kong has a comprehensive collection of historical aerial photographs that are accessible to the public. These aerial photographs have long been an important source of information for geotechnical studies. Conventionally, aerial photograph interpretation (API) and photogrammetric analysis are carried out by skilled personnel using stereoscope and stereo-plotter (Figure 1). The work can now be undertaken by digital means via digital photogrammetry, with improved efficiency, resolution and analytical capability. It is carried out by digitizing a pair of aerial photographs with the use of a high precision and high resolution scanner, processing the digitized data together with the available control point data by an advanced digital photogrammetry algorithm, and displaying the stereo-images and processed data on a computer monitor (Figure 2). Standard, off-the-shelf hardware and software packages are available for digital photogrammetric analysis and presentation of the results. The set-up cost is around HK$ 0.5 million. After setting up, the digital photogrammetry system is neither costly nor difficult to operate, particularly for personnel with API or surveying experience.

Digital photogrammetry has a number of notable applications to geotechnical work. These include:

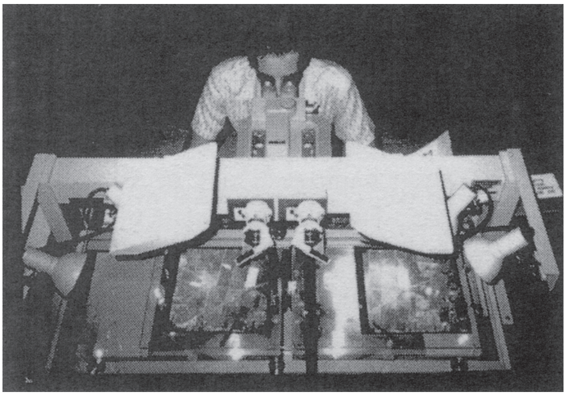


Figure 1. Stereoscope used in conventional aerial photograph interpretation

Figure 2. Digital photogrammetry workstation (Note: stereo view displayed on computer monitors)

(1) Stereo visualization and API

With the ability to display 3-D stereo images on a computer monitor, stereo views of the present and past conditions of a site can be generated by the available historical aerial photographs and stereo visualization is easy, even for people without API training. Furthermore, it is feasible for API to be done and evaluated jointly by a team (Figure 3), which greatly facilitates communication and discussion. Good resolution can be achieved, e.g. up to about 0.1 m for vertical aerial photographs taken at 4,000 feet. Remote sensing and image analysis techniques can be applied to the digitized images for terrain evaluation and feature identification. This provides an objective, consistent and less operator-dependent means of analyzing the aerial photographs, which supplements conventional API using stereoscopes.

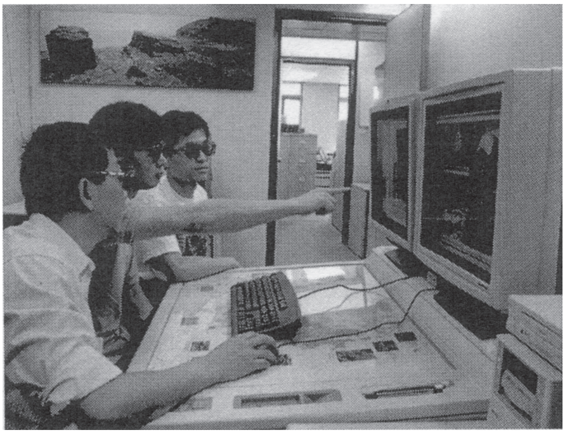


Figure 3. Aerial photograph interpretation by a team using digital photogrammetric technology

(2) Surveying and measurement

Comprehensive data on topography and feature dimensions can be derived from a pair of aerial photographs by digital photogrammetry, without the need for detailed land surveying work. A spatial accuracy of about 0.5 m to 1 m is achievable in Hong Kong, and this can be further improved with the use of low-flight photographs and additional ground control points. This accuracy can meet the need of topographic survey and measurement for many routine geotechnical applications, e.g. slope design. In this respect, digital photogrammetry offers an efficient and inexpensive means of remote surveying and measurement. This is particularly useful for geotechnical work that covers a large area, e.g. assessment of natural terrain hazards, and for circumstances where field measurement is dangerous or not possible, e.g. in areas with access problem or unstable slopes.

(3) Movement monitoring

Movement monitoring normally requires a higher degree of accuracy than that commonly required for visualisation and measurement purposes. Hence, digital photogrammetry using conventional aerial photographs (4,000 feet or above) would have limited use in movement monitoring, unless where the movement to be measured is large. Figure 4 shows an example of such application undertaken by the GEO at a large scale landslide site at Ma On Shan. Use of low-flight aerial photographs (e.g. taken at 500 feet) or terrestrial photogrammetry can give a better accuracy (e.g. Hanson and Lichti

(a) Ma On Shan landslide site

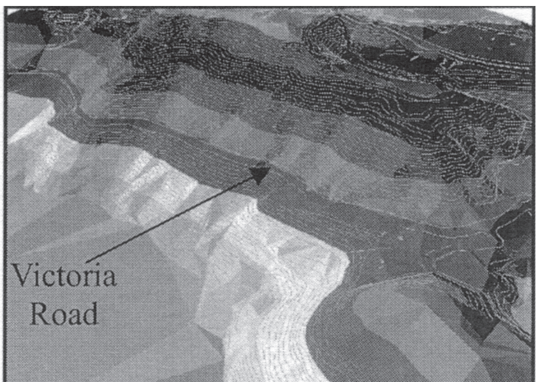
(b) Marker installed on site for use as reference point in digital photogrameteric analysis

Figure 4. Slope movement monitoring at Ma On Shan by digital photogrammetry

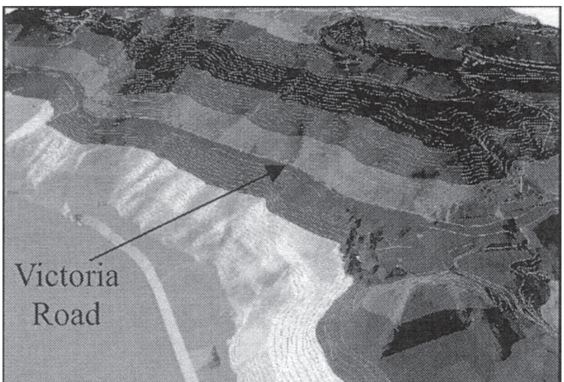
2002; Li and Mo 2003), and there is scope for technological development in this area.

(4) Compilation of digital terrain model (DTM)
Digital terrain model (DTM) is a specific surveying and measurement product of digital photogrammetry that has important 3-D GIS and virtual reality application. Hong Kong has a full set of 1: 1,000 Land Information Centre topographic maps, which can be used to generate DTM. Digital photogrammetry can provide supplementary DTM for areas where elevation data (i.e. contour lines and spot heights) are missing, or where more accurate DTM is required, or where the DTM of the site conditions in the past is required. However, in generating DTM by digital photogrammetry, due account should be taken to map the ground surface in area where vegetation is present. The GEO is about to complete a project to upgrade the current HK-wide 5 m-grid DTM to 2 m-grid. Improvement has also been made in the provision for breaklines, such as drainage lines, roads and slopes, to remove artifacts and enhance the accuracy of the DTM in modeling ground features (Figure 5). This DTM will enable a more realistic representation of the terrain components and morphology, as well as improve the accuracy of geotechnical and other spatial assessments that require the use of 3-D topographic data.

(5) Production of ortho-rectified images
By application of digital photogrammetric techniques, conventional aerial photographs can be converted into ortho-rectified images. Such images are true to scale and position-accurate, which can supplement or even replace survey plans (Figure 6). Ortho-rectified images contain rich visual details of the ground at the time of taking the aerial photographs and are most suited for use in field reconnaissance and mapping. A list of the HK-wide ortho-rectified images available in the GEO is given in Table 1. As ortho-rectified images are

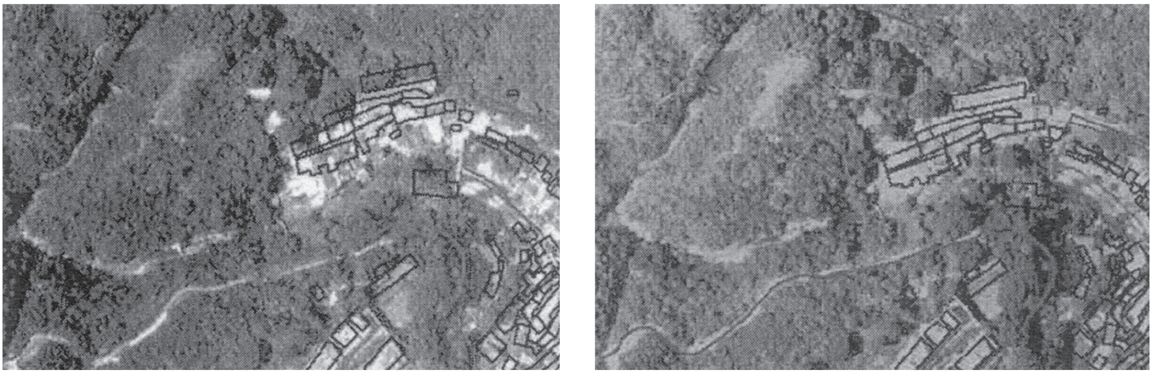


(a) 5-m grid DTM



(b) 2-m grid DTM with enhancement (Note: roads and man-made slopes are correctly modelled in the DTM)

Figure 5. Enhanced 2 m-grid digital terrain model (DTM)



(a) Ordinary aerial photograph
(Note: not to scale and position-inaccurate)

(b) Ortho-rectified image
(Note: true to scale and position-accurate)

Figure 6. Conversion of ordinary aerial photograph to ortho-rectified image

in digital and geo-referenced format, they can be integrated into a GIS together with other spatial data for a range of novel GIS and remote-sensing applications. These include: geotechnical field mapping, GIS data mining, feature recognition and extraction, change detection and monitoring, and virtual reality. A notable application to mapping of boulders using image processing techniques is reported in Shi et al. (2004).

Table 1. List of HKSAR-wide ortho-rectified images held in GEO

Type of Image	Year	Color	Resolution
Satellite images (LandSat & SPOT 40+ sets)	1987 onward	Color	10 m +
Low-flight aerial photographs	1963(1)	Black and White	0.1 - 0.5 m
	1973/74(1)	Black and White	0.5 m
	1982(1)	Black and White	0.5 m
	1993(1)	Black and White	1.0 m
	2000(2)	Color	1.0 m
	2001(2)	Color	1.0 m
	2002/3(2)	Color	0.5 m
Infra-red images	2000(3)	Infra-red	0.35 m
	2000(4)	False-color	0.35 m

Notes: (1) ortho-rectified by GEO
(2) ortho-rectified by Lands Department
(3) compiled by Chinese University of Hong Kong
(4) converted by GEO

GEOGRAPHIC INFORMATION SYSTEM (GIS)

Development of Capability

Geographic Information System (GIS) has been adopted in Hong Kong for several years in recording and managing geotechnical data. By nature, most geotechnical data contain spatial attributes on their geographic location (x, y, and z) and on the geometry of the ground/object (e.g. point, line or polygon) represented by the data. Managing the data in GIS would register the spatial attributes and permit the use of the attributes in GIS related application, resulting in improved capability and efficiency.

Given its geotechnical mandate, since early 1990s the GEO has been a key party in developing geotechnical spatial datasets and GIS capability and promoting GIS application to geotechnical work in Hong Kong. In the early years, the development and application work focused on the following areas:

(1) Compilation of GIS datasets, including conversion of existing data into GIS format and collation of new data. Important GIS datasets that are frequently used in geotechnical work (Figure 7) include:

- Topographic and land information maps covering the whole of HKSAR in various scales, up to 1: 1,000 scale
- 1:20,000 scale geological maps covering the whole of HKSAR and 1:5,000 scale for some development areas
- A catalogue of 57,000 registered man-made slopes including slope related information
- An inventory of over 30,000 historical natural terrain landslides
- An inventory of about 2,000 large (scar > 20 m wide) natural terrain landslide features
- An inventory of landslide incidents reported to the GEO since 1984
- 5-minute rainfall data since 1985 from about 100 nos. of raingauges

- Ground investigation data
- 5 m-grid DTM, which is being upgraded to 2 m-grid
- About 50 sets of ortho-rectified images covering the whole of HKSAR (Table 1)

(2) Development of GIS systems and capability, such as:

- Setting up software and hardware systems
- Developing GIS skills among professional and technical users, typically through short courses and on-the-job training
- Integrating GIS datasets and setting up centralized database for enhanced system management

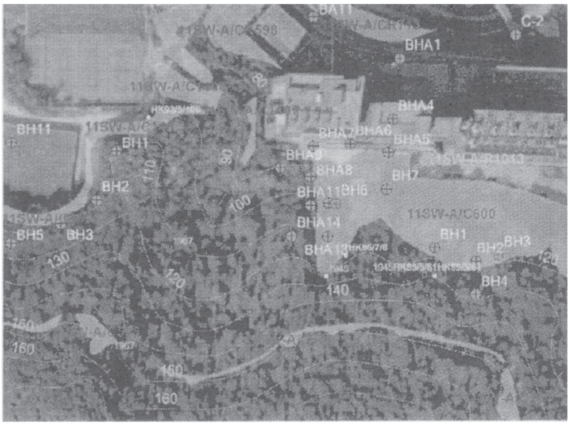


Figure 7. Selected geotechnical GIS datasets (Note: ortho-rectified infra-red image of year 2000, contour lines, registered man-made slopes, historical natural terrain landslides, reported landslide incidents and ground investigation data as shown)

- Acquiring Intranet, Internet and mobile GIS capabilities for ‘enterprise-based’ and other functional GIS applications, which involve use of specialized GIS modules, e.g. Spatial Database Engine and Internet Map Server for different scalable GIS applications. This development was however confined to key GIS users, such as the GEO and the Jockey Club Research and Information Centre (JCRIC) for Landslip Prevention and Land Development in the University of Hong Kong.

(3) GIS applications, which mainly focused on data management and information services. A number of state-of-the-art GIS systems were set up in Hong Kong in the late 1990s and early 2000s, e.g. GEO's Slope Information System (Figure 8), Fill Management System, Geological Modeling System and Aerial Photograph Management System (Figure 9), and the Comprehensive Ground Information System and Electronic Mark Plant Query System of JCRIC. These GIS systems are primarily used for data management and information services, with basic GIS search and browsing functionalities provided to users, without using a GIS software to interact with the systems.

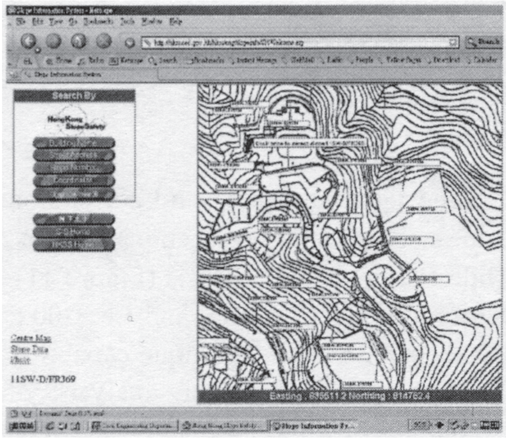


Figure 8. Slope Information System

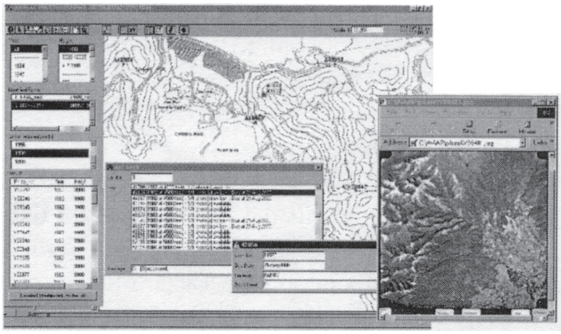
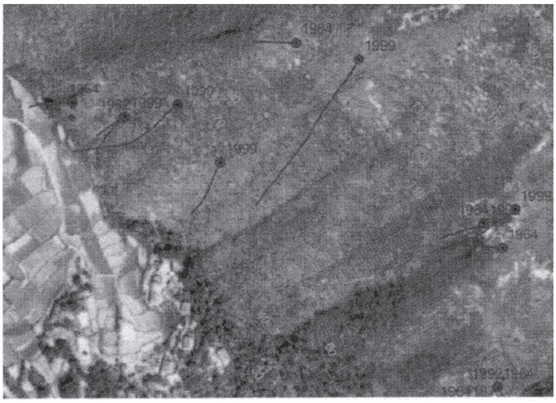


Figure 9. Aerial Photograph Management System (Note: the system supports spatial search of aerial photographs covering the site concerned from over 120,000 nos. aerial photographs held in GEO’s Aerial Photograph Library)

Application Trend

While GIS data management and information services remain important, the trend in recent years is to adopt more advanced GIS functionality to deal with geotechnical issues in Hong Kong. This is possibly the result of building up of GIS capability among the geotechnical profession as well as increased demand for use of GIS in solving geotechnical problems. Some notable applications are described below:

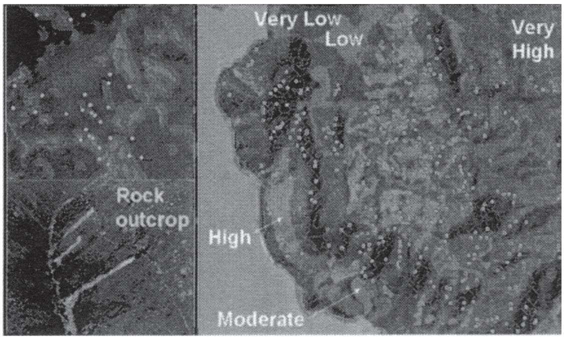
(1) Advanced GIS search, browsing, editing and publication
This is performed by more skilled GIS users via the use of GIS tools, say, in a geotechnical desk study to examine the available geotechnical data, review the site history and assimilate the key information for presentation (Figure 10). Advanced GIS search would enable users to query and retrieve data that meet certain prescribed criteria or geographic relationship. Examples of such application include delineation of area of deep rock weathering using ground investigation data, search of man-made slope features for stability assessment, and



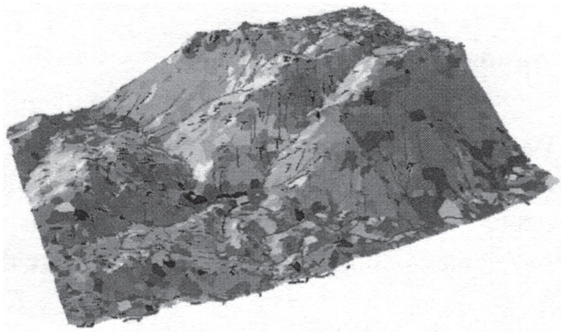
(a) Site in 1963

(b) Site in 2000 (Note: there are recent landslides on the natural hillside and new developments below the hillside)

Figure 10. Use of GIS in geotechnical desk study

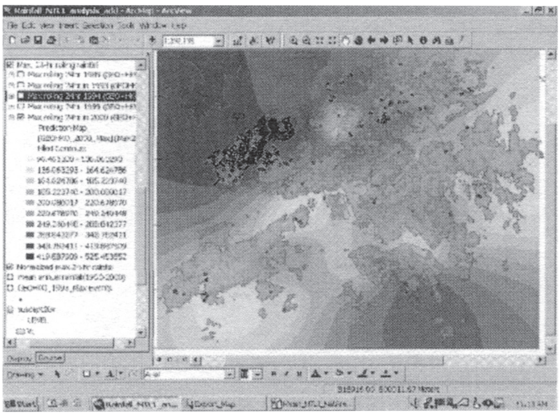


(a) GIS analysis and correlation of terrain with different levels of landslide susceptibility

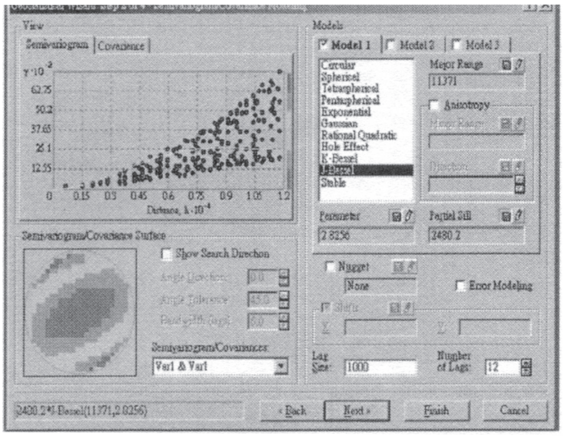


(b) 3-D visualization of historical landslides and terrain with different slope gradients

Figure 11. GIS-based natural terrain landslide susceptibility analysis



(a) Year 2000 maximum rolling 24-hr rainfall and natural terrain landslide locations



(b) GIS-based geo-statistical analysis

Figure 12. GIS analysis of natural terrain landslide-rainfall correlation

identification of sites affected by historical natural terrain landslides.

(2) GIS analysis

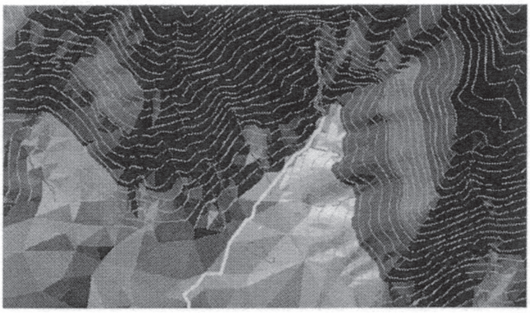
GIS analysis can be performed efficiently to examine the relationship and correlation among different spatial data, which are difficult to analyze using conventional means. It is now used commonly in natural terrain landslide susceptibility analysis (Figure 11), as part of Natural Terrain Hazard Study (e.g. Evans and King 1998; Dai and Lee 2002; OAP 2003; Halcrow 2003; Wong 2004). GIS analysis also offers a unique capability in geotechnical research and development work involving spatial analysis of geotechnical data. Figure 12 shows a recent example where the correlation between natural terrain landslide density and rainfall intensity in Hong Kong has been established using GIS analysis together with GIS-based geo-statistics (Ko 2003).

(3) GIS modeling

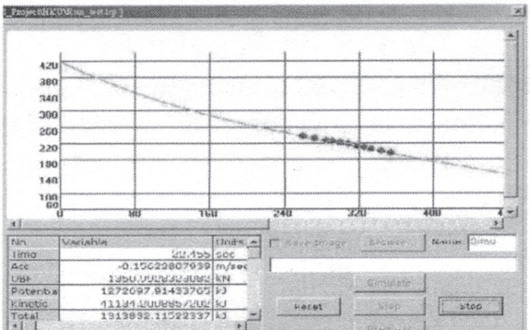
In additional to GIS analysis that is principally applied to assessing the spatial relationship among the data, performing GIS-based geotechnical analysis and numerical modeling based on application of engineering principles and governing physical laws has become increasingly important. Such application integrates engineering analysis with GIS, and is a powerful modeling tool, particularly for dealing with geotechnical subjects that involve the analysis of the geographic and engineering attributes of a large amount of spatial data. Development of GIS modeling applications requires GIS programming input from skilled personnel. Two geotechnical examples of such application in modeling the mobility of landslide debris and natural terrain landslide quantitative risk assessment are shown in Figures 13 and 14, respectively.

(4) Mobile, location-based application

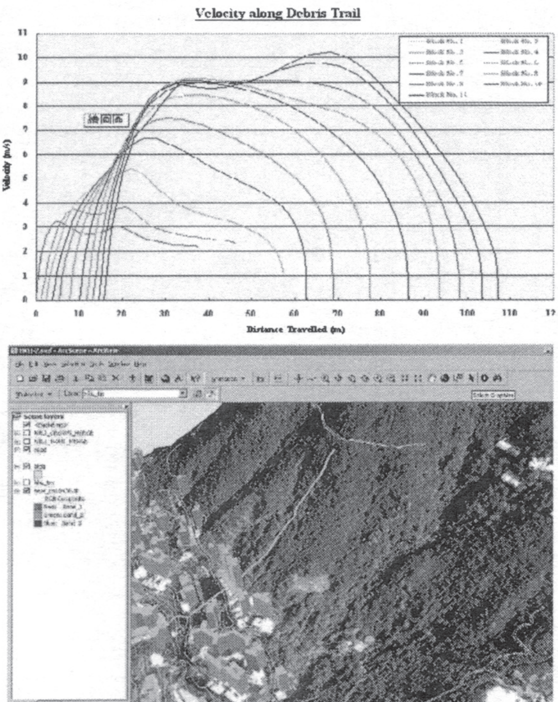
Geotechnical professionals spend considerable time and effort in field work, which is an important component of geotechnical practice. GIS can now be brought to site and applied to field work, by uploading the relevant datasets onto a mobile GIS platform that operates on a pocket computer. When integrated with a Global Positioning System (GPS) for detecting the spatial location on site, a mobile GIS system can guide on-site navigation to the point of interest (Wong 2001). In addition, the spatial data relevant to the site can be retrieved for location-based applications. The GEO has pioneered the development of a state-of-the-art GIS-GPS mobile mapping system that also incorporates the use of ortho-imagery. The system is equipped with wireless telecommunication via the Internet with GEO's GIS Internet Map Server, for GIS data transfer for use in geotechnical field work (Figure 15). This system was granted an



(a) Generation of debris flow path



(b) Computation of debris flow path



(c) Presentation of results

Figure 13. GIS modeling of debris mobility

Figure 14. GIS-based landslide quantitative risk assessment (Note: hazard and consequence models are incorporated into the GIS for calculation of risk using the relevant spatial data of the catchments and facilities at risk; catchments and facilities with different levels of calculated risk shown in different colours)

international 'Special Achievement in GIS Award' in 2002 in recognition of its technological advances and benefits to the engineering field. Details of the system and its application are described in the paper by Ng et al (2004).

(5) 3-D visualization and virtual reality applications

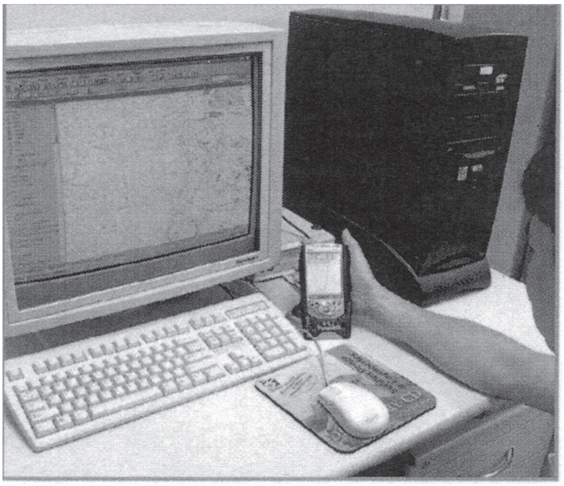
3-D GIS technology is maturing. Production of 3-D topography, city model, etc. has become relatively easy using the available spatial data, DTM and ortho-rectified images. Geotechnical professionals with GIS skills can now generate 3-D ground model and visualize the site conditions (Figure 16) on their desktop computers. This facilitates geotechnical studies, e.g. in reviewing historical landslides and terrain evaluation (Wong 2001). Virtual reality animation and computer 'fly-through' can be produced for presentation and evaluation purposes without the need for input from specialists in 3-D computer graphics.

INTERFEROMETRIC SYNTHETIC APERTURE RADAR (InSAR)

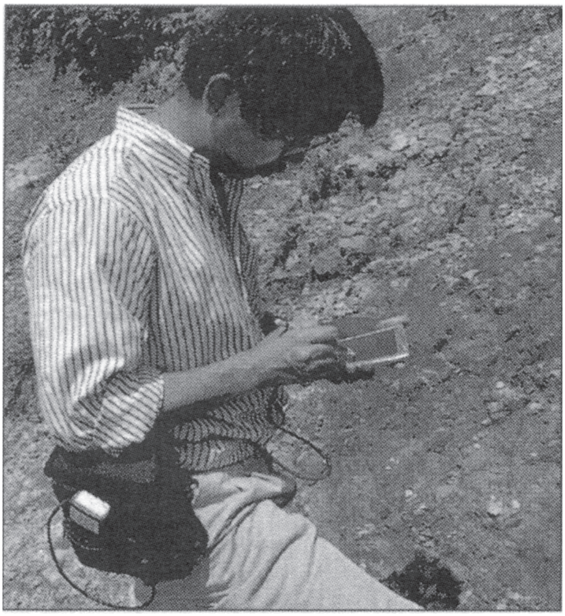
Interferometric Synthetic Aperture Radar (InSAR) is an emerging remote sensing technology that could measure ground displacements with millimeter-level accuracy. Each pixel of a Synthetic Aperture Radar (SAR) image contains information on the phase of the signal backscattered from the terrain surface. By applying interferometry to a pair of SAR images of an area, the geometry of the two slightly displaced, coherent observations of the surface would give their phase difference, which is a function of the surface height. Through repeated observations, it is possible to measure the surface displacement if ground movement has occurred over the observation period.

InSAR has been successfully applied to measurement of surface movement over large area induced by earthquakes (e.g. Massonnet et al. 1993), volcanic activities (e.g. Lu et al. 2002), ground subsidence (e.g. Fielding et al. 1998), etc. Some cases of application to detection of slope movement have also been reported (e.g. Strozzi et al. 2001). It is potentially a promising low cost, high accuracy remote sensing technique for geotechnical use, particularly for ground and slope movement detection.

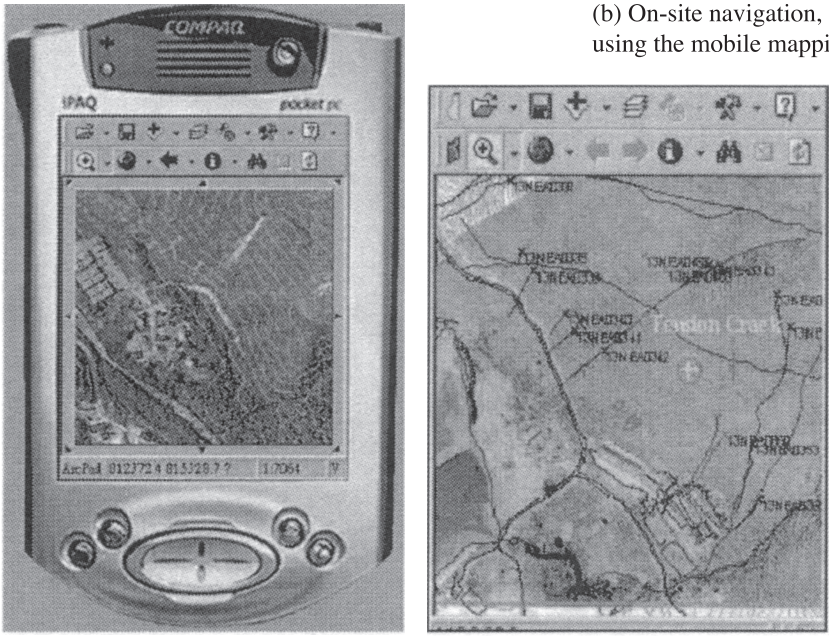
InSAR has been tried with encouraging results in Hong Kong in detection of reclamation settlement (Ding et al. 2004b). In collaboration with the Hong Kong Polytechnic University, the GEO has recently



(a) Uploading GIS data to the mobile mapping system



(b) On-site navigation, data retrieval and mapping using the mobile mapping system



(c) GIS data and ortho-rectified image together with GPS location shown on pocket computer

Figure 15. Geotechnical mobile GIS mapping system

completed a trial application of InSAR for detection of slope movement and ground deformation at four selected sites in Hong Kong. The trial study shows that the available satellite-based SAR images are not very suitable for reliable InSAR analysis for the typical urban setting in Hong Kong (Figure 17). Further information on InSAR application in Hong Kong is reported in Ding et al. (2004a).

A realistic appreciation of the current limitations of the technique and good awareness of its development potential are essential to successful application. In this respect, the following constraints on using of satellite-based InSAR in Hong Kong are note-worthy:

- Many of the available SAR images have large Doppler Centroid Frequency and low coherence, particularly for long time-span. These result in poor quality interferograms, which affect the reliability of InSAR analysis.
- SAR images have low spatial resolution (each pixel typically > 10 m). Hence, the interferogram

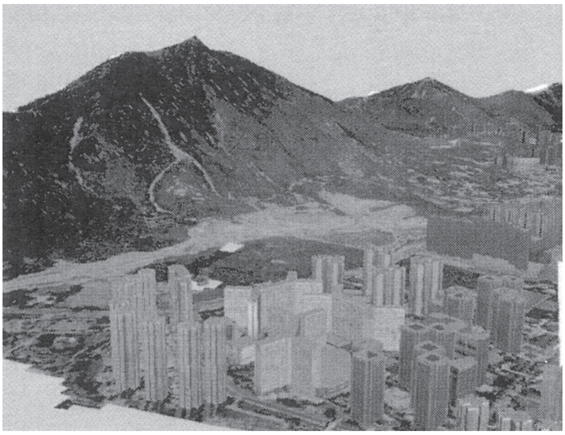


Figure 16. 3-D virtual reality model of Tsing Shan Footfills

only shows the average condition for each pixel and any surface movement that may be measured is at best representing the overall movement in the pixel. Hence, InSAR is more suitable for use in spatially extensive sites that are without drastic changes in surface profile and significant variations in ground movement over short distance. If the site to be measured is small in size (e.g. a relatively small-sized man-made slope) or if local changes in ground profile and ground movement are significant, it is difficult to apply satellite-based InSAR.

- InSAR results can be seriously affected by noises, such as those arising from geometric distortion, atmospheric effects and temporal decoration. Geometric distortion can be a serious problem for applying InSAR to steep terrain in Hong Kong. Also, the relatively humid environment and presence of thick vegetation imply that atmospheric effects and temporal decoration would be more significant in Hong Kong, than in other countries that have a more favorable site setting for successful use of InSAR.

The quality and availability of SAR images would improve as more satellites are launched. Development of airborne and land-based InSAR would reduce noise effects and enhance the accuracy and spatial resolution of InSAR results. InSAR technologies, e.g. use of reflectors, filters and permanent scatter techniques, are evolving. The GEO is arranging the installation of a number of comer reflectors in selected sites in Hong Kong. This will provide an opportunity for testing the improvement that may be achieved and for developing the long-term potential for geotechnical application of InSAR in Hong Kong.

LIGHT DETECTION AND RANGING (LIDAR)

Light Detection and Ranging (LIDAR) is a promising

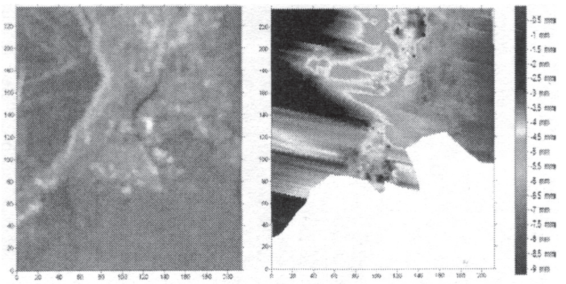
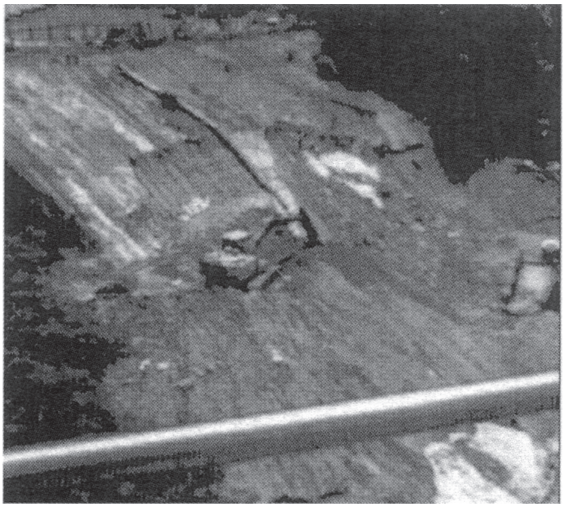
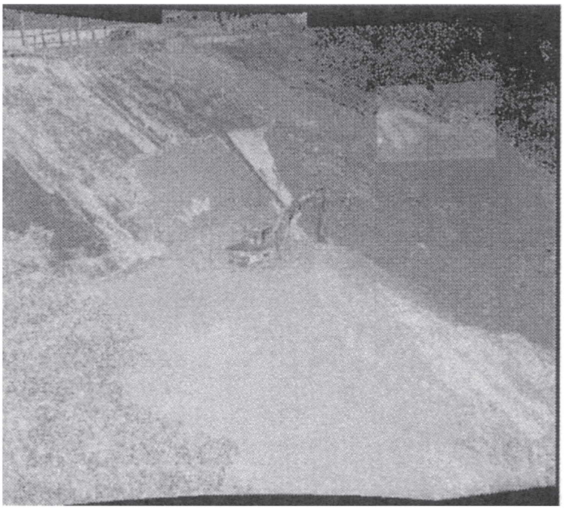


Figure 17. Trial InSAR application for detection of slope movement in Hong Kong (18.3.1996 to 9.11.1999 3.6-year InSAR results at Tsing Shan Foothills, which are significantly affected by 'noises', as shown)

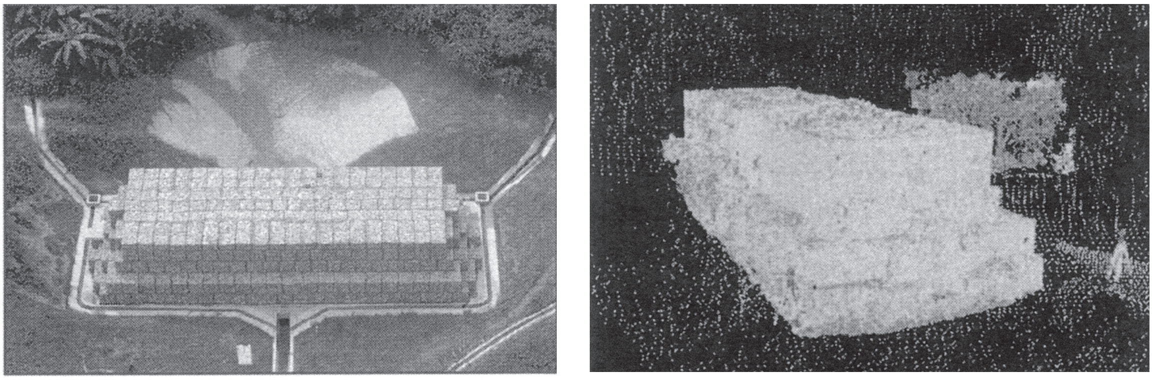


(a) Landslide site



(b) LIDAR point clouds

Figure 18. LIDAR survey of a landslide site



(a) Debris-resisting barrier (b) 3-D digital LIDAR model

Figure 19. 3-D digital model compiled by LIDAR

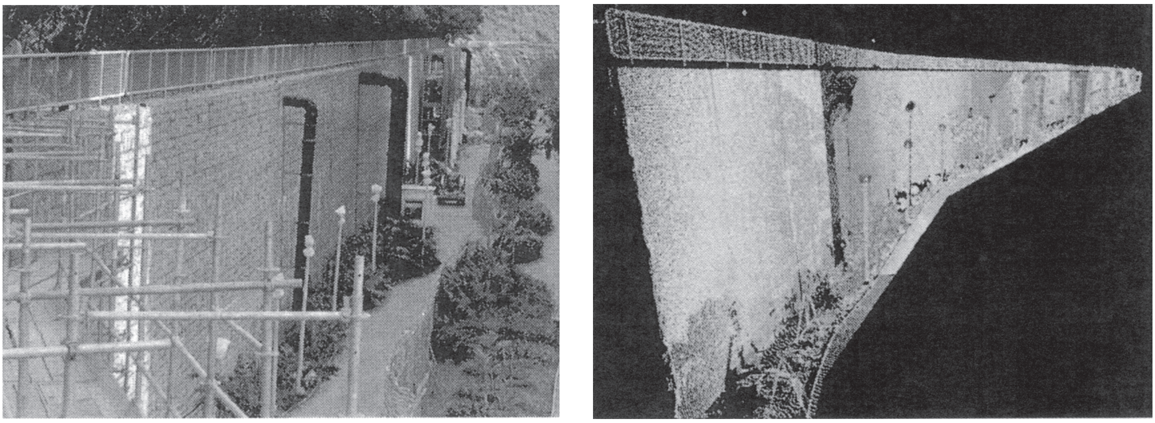


Figure 20. Use of LIDAR in monitoring movement of a retaining wall

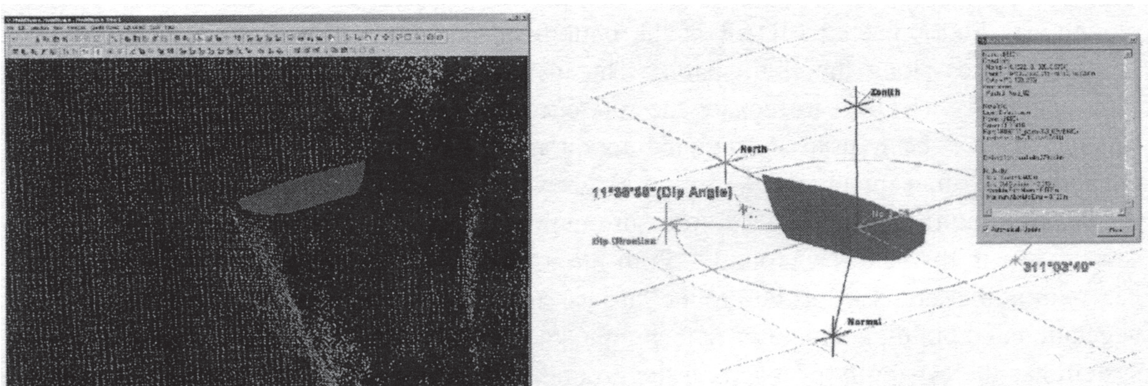


Figure 21. Use of LIDAR in rock joint mapping and survey (Note: the blue area is a joint plane on a rock face with the joint orientation measured by LIDAR)

remote-sensing tool for scanning surface topography by measuring the direction and time of sending and receiving coherent laser beams to the objects of interest. State-of-the-art land-based LIDAR capability is available in Hong Kong. Such land-based LIDAR system, commonly denoted as 'laser scanner' in Hong Kong, has the capability of measuring, 3-dimensional point clouds of objects within about 150 m along the line-of-sight. The laser scanner emits thousands of laser beam pulses per second for measuring a 'window' of 3-dimensional surfaces. The positional accuracy is within 6 mm in a 50-m range. The point clouds, apart from providing spatial information on their x, y, and z coordinates, contain an intensity signal of the laser reflection and hence present a 3-D false-color digital model of the scanned object.

The GEO has been using the laser scanner in topographic surveys, which is particularly useful where physical access to the survey site is difficult or dangerous, e.g. a new landslide scar (Figure 18). Similar application of laser scanner in surveying a full-scale test of fill slope failure has also been reported by Kwong (2003).

LIDAR can be used in many novel geotechnical applications apart from topographic survey, such as:

(1) Construction of high-resolution DTM - given the high sampling density, DTM produced by LIDAR can enhance the quality and supplement the DTM produced from the available topographic maps and from digital photogrammetry.

(2) Compilation of 3-D digital models of slopes, debris-resisting barriers, structures and other geotechnical features (Figure 19) - this assists construction monitoring and provides an accurate and detailed virtual reality records for use in future maintenance and modification work.

(3) Movement monitoring of slopes and structures (Figure 20) - movement can be detected and monitored by comparing LIDAR results obtained at different time; there is however a need to register the key data of common observation points in different LIDAR surveys to ensure accuracy and efficiency.

(4) Rock slope mapping and rock joint survey (Figure 21) - by judiciously matching and analyzing the LIDAR point clouds.

Customization and development work, which is essential for tailor-making the available technique for efficient and effective geotechnical use, is being pursued by the GEO and local academic institutions. Table 2 summarizes the key customization and development work currently undertaken by the GEO on the novel LIDAR applications identified (Wong 2003).

Airborne LIDAR, which can survey a large area efficiently and at competitive cost, is subject to active technological development in other advanced countries where there is a demand for high-resolution topographic data. Airborne LIDAR is typically performed by mounting a high-powered LIDAR at the bottom or sides of a plane/helicopter to scan the ground features along the flight path. The instrument is bundled with accurate onboard differential GPS (DGPS) to register the reference plane and positioning during the LIDAR survey. It has been used in regional topographic mapping and construction of DTM, typically with an accuracy of ± 15 m in height value. An important recent development is the use of a multi-return LIDAR to measure multiple returns for each laser pulse that covers several feet in diameter on ground. With the use of an advanced numerical algorithm, the last returns that come from the ground surface are extracted by filtering other returns from vegetation and building structures (a technique known as ‘virtual deforestation’). Hence, the system has the capability of mapping the ground surface of vegetated terrain (Haugerud and Harding 2003). The technique has been used to produce fine-scale topographic maps and DTM typically with grid size of about 1 m. This allows landslide geomorphology to be interpreted and landslide maps to be produced to a resolution that cannot otherwise be achieved by using conventional aerial photographs. It is recognized as one of the most important remote-sensing tool for obtaining high-quality digital elevation data and for landslide hazard mapping (National Research Council 2004). However, its applicability in Hong Kong is yet to be tested.

Table 2. LIDAR customization and development work (extracted from Wong 2003)

Customization and Development Work	Applicable to Item No.			
	(1)	(2)	(3)	(4)
Optimization of the techniques and processes for re-sampling and conversion of the LIDAR data, for use on other digital platforms, e.g. GIS, CAD and digital photogrammetry systems	✓	✓	✓	✓
Building of slope and structure monitoring models using LIDAR data, and development of methods for change detection		✓	✓	
Development of methodology for LIDAR mapping of rock slopes and survey of rock joints, possibly in combination with use of digital photogrammetry and image analysis techniques				✓
Assessment of the optimal details to be contained in 3-D virtual reality records, and examination of suitable methods and platforms for use in compiling and managing the records		✓	✓	

Legend: (1) = Construction of DTM
(2) = Compilation of 3-D digital models
(3) = Movement monitoring
(4) = Rock slope mapping and joint survey

CONCLUSIONS

Hong Kong has been actively pursuing the development and geotechnical application of novel digital technologies. This has led to improved capability and efficiency. The geotechnical profession should continue to maintain awareness of the technological development and opportunities for geotechnical application. Digital photogrammetry and GIS are examples of novel digital technologies that have successfully been integrated into our geotechnical practice. InSAR and LIDAR are emerging techniques that have notable potential. Development and customization work, which will further enhance their capability and suitability for geotechnical application, is being undertaken in Hong Kong and elsewhere.

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