

# APPLICATION OF SATELLITE TECHNOLOGY TO ENVIRONMENTAL GEOTECHNOLOGY

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# Application of Satellite Technology to Environmental Geotechnology

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**ABSTRACT:** Ground subsidence is one of the most serious environmental geotechnology problems in Taiwan. It has been reported that about 1170km<sup>2</sup> of land has settled during the past few decades due to extraction of groundwater. Recently, the Government sponsored a research which is aimed at providing guidelines for better control of ground subsidence. One of the major tasks of this research is to introduce satellite technology in the study of ground subsidence. Global Positioning System (GPS) has been successfully applied in this study. The major concern of the GPS application is its accuracy in vertical direction. This study indicates that the root-mean-square difference between level survey and GPS can be controlled to be within 2cm which is acceptable for study in large areas with significant subsidence. Since satellite image can now be relatively frequently and economically obtained, it has become an extremely useful data in the control of land use. This study introduced the use of neural network concept to process the images from Satellite SPOT. It can identify the characteristics of land with reasonable accuracy. The processed image can then be incorporated in a Geographic Information System (GIS) for land use control. The successful use of satellite technology in this study indicates that further applications of these techniques in environmental geotechnical problems are very encouraging.

## INTRODUCTION

Ground subsidence is one of the most serious environmental geotechnology problems in Taiwan. The total area of Taiwan Island is 36000km<sup>2</sup>. It has been reported that about 1170km<sup>2</sup> of land has settled during the past few decades due to extraction of groundwater. Many coastal areas have even been seriously flooded during typhoon seasons. Considering two thirds of the land in Taiwan is mountainous, the ground subsidence area does occupy a significant portion of very valuable land which can be used for living, agriculture and industry. This ground subsidence issue has caught more attention in the last few years since the Government announced the "Six-Year Development Plan". The total budget of this plan is approximately 300 billion US dollars of which more than 100 billion dollars will be spent on infrastructures. These infrastructures include highways, rapid transit systems, high speed railway, and other engineering facilities. Some of the major constructions will be located in ground subsidence areas.

Many studies on ground subsidence have been conducted in different areas in Taiwan. Most of these studies use conventional survey methods and monitoring instrument to measure ground level and groundwater pressure. Since the impact of ground subsidence becomes more significant to the future development in Taiwan, the Public Construction Supervisory Board of the Executive Yuan (Cabinet) in 1991 commissioned Moh and Associates, Inc. to carry out a study which is aimed at providing guidelines for better control of ground subsidence (MAA, 1992; MAA, 1993). This research is methodology-development in nature. One of the major tasks of this research is to introduce the state-of-the-art technology to future study on ground

subsidence problems. Of particular interest to this paper is the application of satellite technology: Global Positioning System (GPS) is used to measure the ground elevation and the French Satellite SPOT images are used to characterize land use.

## SITE CONDITION

The study site is Yong-An area in Kaohsiung County. It is located in the southwest coast of Taiwan (Fig. 1). Yong-An is one of the most extensively monitored ground subsidence areas in Taiwan. Because of the deep well pumping for fishery, Yong-An area has experienced significant ground subsidence since early 1980s. In addition to this regional ground subsidence, settlement problem is more severe in two major industrial facilities in this area. They are the Hsinta Power Plant and the Liquefied Natural Gas (LNG) Receiving Terminal located in the north and south side of Yong-An, respectively. Both of these two facilities were built on reclaimed land. For successful operation of these facilities, settlement of the reclaimed land itself and settlement caused by surcharge load of the heavy industrial equipments should be taken into account. The settlement problem is even more complicated in the LNG Receiving Terminal. In order to build 7 underground storage tanks of 100,000kl capacity each, diaphragm walls of 1.2m thick and 54.5m long have been constructed. The groundwater has to be lowered during excavation. In 1986, the pumping used to lower the groundwater in the excavation has caused significant groundwater drawdown and consequently serious settlement of the site.

Figure 2 presents the typical soil profile of the study

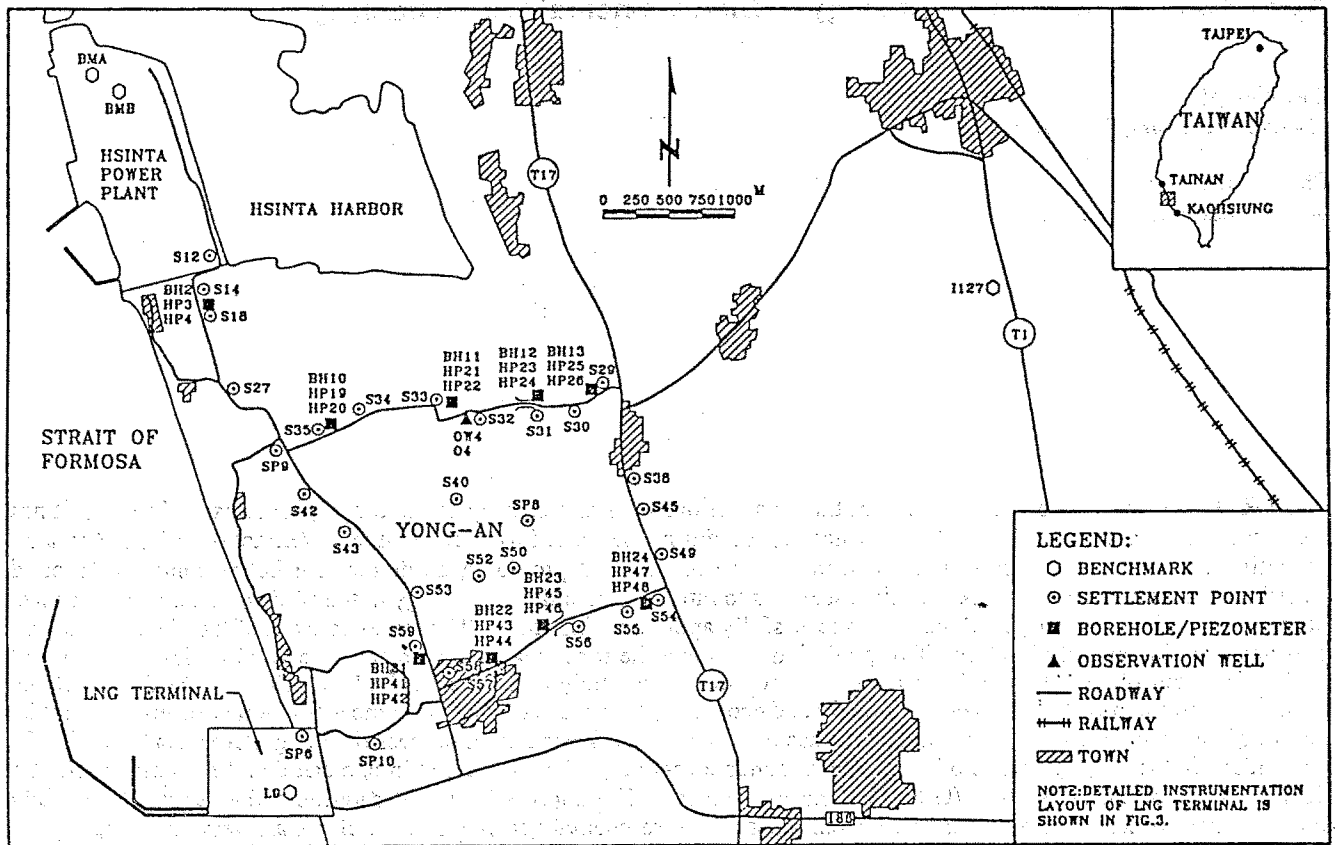


Figure 1. Typical Soil Condition of the Study Area

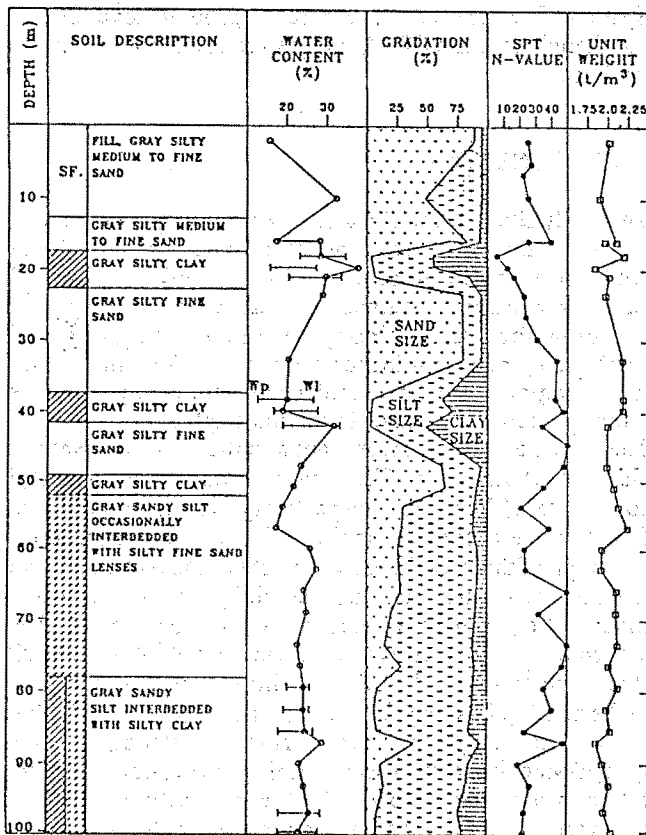


Figure 2. Soil Profile of the Study Area

area from ground surface to the depth of 100 m. Underlying surface soil are alternating silty sand and silty clay layers with depth down to approximately 52 m. Between the depths of 52 m and 78 m is a sandy silt layer with silty fine sand lenses. Below this layer is a thick interbedded sandy silt and silty clay layer. Other deep borehole information indicates that there is a gray silty clay stratum located between the depths of 100 and 200 m approximately. The groundwater table is very close to the ground surface, but the groundwater pressure in deep layer is significantly lower than the hydrostatic pressure.

### MONITORING INSTRUMENTS

The general layout of the monitoring instruments in Yong-An is shown in Fig. 1. Figure 3 presents the detailed layout of the instruments in the LNG Receiving Terminal. Monitoring of ground subsidence and groundwater variation has been carried out in many stages by various engineering and research institutes in the last few years. Total settlement at ground level, compression of each soil stratum, and variation of groundwater pressure are monitored.

Level survey has been conducted to measure the elevation change of the shallow settlement points as well as the deep benchmarks. In this study, Wild NA3000 Electronic Level was used. In addition to the conventional level survey, the ground elevation has also been measured by the use of GPS. It will be further discussed in the following section.

Compression of each stratum has been measured by extensometers. Both rod extensometers and SONDEX

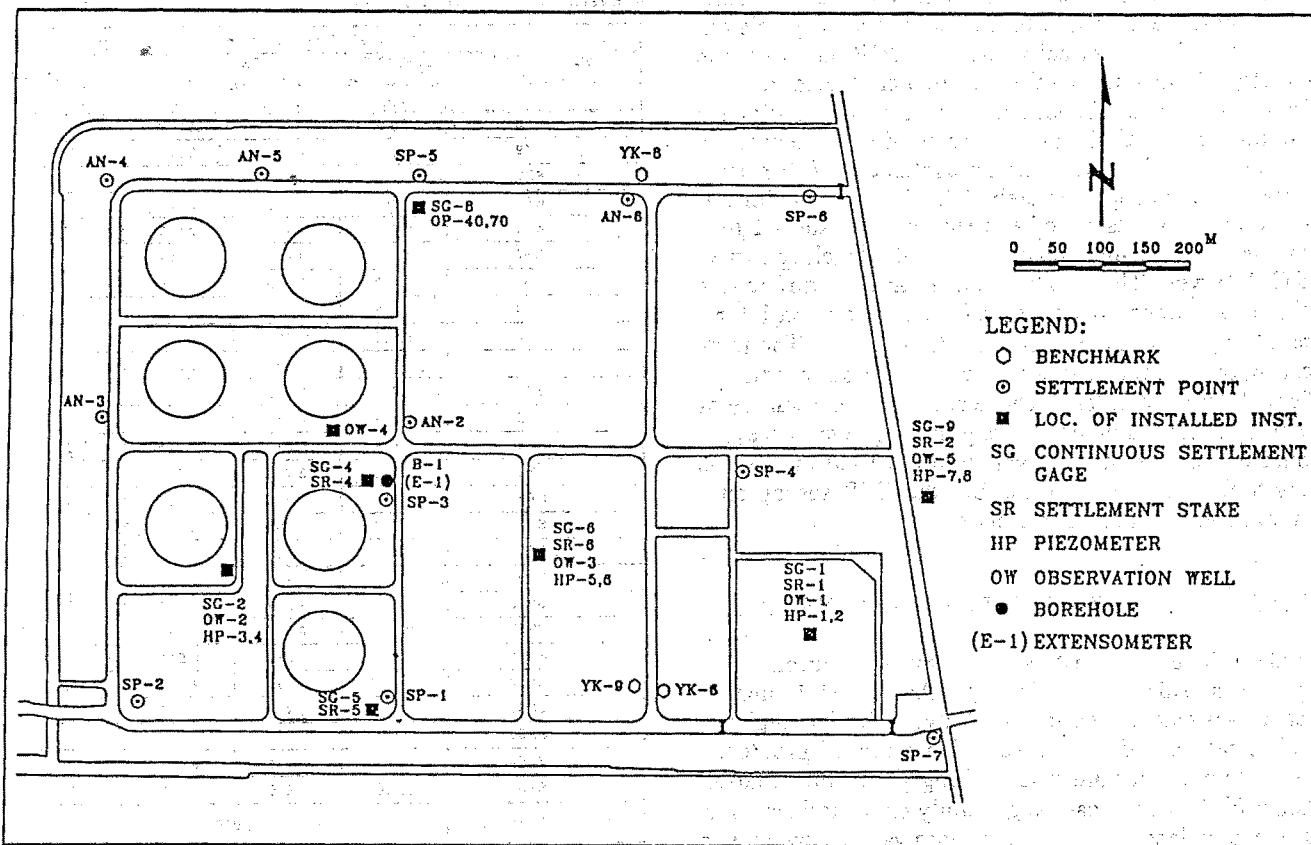


Figure 3. Instruments Layout in LNG Receiving Terminal

system have been used. Measurement of the compression of each stratum is critical to the prediction of the amount and duration of the settlement. With the long-term monitored compression and groundwater pressure data of each layer, back analysis can be conducted. Soil properties of each layer can be estimated, as well as the analysis model can be calibrated. The back-analysis results can then be used for prediction of future settlement of this site.

Groundwater pressure was measured by means of observation wells and piezometers. In this area, hydraulic-type, pneumatic-type and electronic-type piezometers have all been used. Groundwater monitoring results provide extremely useful information in understanding the ground subsidence mechanism of the region.

### GLOBAL POSITIONING SYSTEM

The Global Positioning System (GPS) is developed by the U.S. Department of Defense. It is a satellite-based positioning system to support military navigation and timing needs. Once fully operational, it will consist of 24 satellites arranged in six orbital planes. The orbit is at an altitude of 20,200km above Earth with a 55° inclination. Currently there are 22 operational satellites which can allow for use of the system in Taiwan for almost 24 hours a day with good geometric distribution. During the surveying period, there existed 18 operational satellites. The absolute position of a ground point can be determined from a GPS receiver at this selected point receiving signals from at least 4 simultaneously observed satellites. With only one GPS receiver, the accuracy of the absolute positioning is not

sufficient for engineering surveys. If two or more ground receivers are used simultaneously, then relative positioning between the two stations can be performed. The error can be reduced to the range of a few centimeters which can be acceptable for some specific uses in engineering practice. Compared to the conventional level survey, GPS is much faster and less expensive. Besides that, GPS survey has several other merits compared with terrestrial surveys (Chrzanowski et al., 1991). Intervisibility between stations is not needed, which simplifies the design of monitoring schemes and allows for the optimal location of points. It also makes it easier to select the reference points outside the subsidence area. In addition, GPS surveys provide simultaneously three-dimensional information on the deformation status. Over the past few years, GPS has been tested and applied in ground movement measurements in various projects such as ground subsidence study in the oil fields in Venezuela (Chrzanowski et al., 1991). The application of GPS to monitor ground subsidence due to water withdrawal (Strange, 1989) and the determination of tectonic movements (Bock & Murray, 1988) have also been reported.

In this study, GPS surveys have been conducted in September 1992, January 1993, and April 1993. Two ground receivers have been mobilized. "Rapid-static" survey method has been adopted in this study. The receivers occupied the station only for a few minutes to collect the data. A commercial software package LEICA SKI was used to process received signals. The working hours selected were dependent on the relative location among the ground receivers and satellites. The index to reflect the effect of the geometrical distribution of the satellites on

the overall positioning accuracy is Geometrical Dilution of Precision (GDOP) which is given as a ratio of the actual positioning/time precision to the measurement precision. The smaller the numerical value of GDOP the better the geometry. In this study, all measurements were taken at GDOP less than 6. Level survey was carried out at the same time as the GPS survey was conducted so that the accuracy of GPS survey can be evaluated. The survey covers an area of approximately 30km<sup>2</sup>. The elevations of 26 settlement points have been surveyed. Tables 1 to 3 compare the measured elevation from the leveling survey and GPS survey. They indicate that the average differences in these 3 sets of comparisons are 0.6cm, 1.0cm and 1.1cm. The average of all the measurements is 0.9cm. The root-mean-square errors of these 3 sets of measurements are 0.9cm, 1.4cm and 1.7cm. The accuracy of GPS survey of this study is comparable to the engineering level survey. It should be noted that the level survey carried out in this study took 7 days each time, but the GPS survey only required two working days at most.

### GROUND SUBSIDENCE INFORMATION SYSTEM

In order to make the best use of all available information in ground subsidence area, Ground Subsidence Information System was established in this study. With its emphasis on the treatment of ground subsidence related problems, this system functionally is a Geographic Information System (GIS) which can be generally characterized as an organized collection of computer hardware, software, and

Table 1. Comparisons between GPS and Level Survey Measurements (Sept., 1992)

September, 1992 Measurement				
SETTLEMENT POINT	ELEVATION (Level Survey) H (m)	ELEVATION (GPS Survey) HI (m)	H-HI (m)	GDOP
YK8	3.937	3.940	0.003	2
YK9				
S55	2.061	2.061	0.000	3
HT1	2.095	2.095	0.000	2
HT2				
AN3	4.087	4.074	-0.013	2
AN2	6.420	6.417	-0.003	2
AN4	4.777	4.776	-0.001	2
AN5	6.040	6.037	-0.003	2
AN6	3.659	3.658	-0.001	2
SP1				
SP2				
SP3	3.857	3.865	0.008	3
SP4	3.746	3.748	0.002	3
SP6	3.981	3.978	-0.003	3
SP7	4.526	4.529	0.003	4
SP8	2.832	2.819	-0.013	2
SP9	1.279	1.280	0.001	3
SP10	1.637	1.639	0.002	3
SP27				
SP31				
SP38	4.110	4.126	0.016	3
SP43	1.452	1.455	0.003	3
SP53	1.574	1.583	0.009	3
SP54				
SP57				
Average Error (m)			0.006	
Root-Mean-Square Error (m)			0.009	

Table 2. Comparisons between GPS and Level Survey Measurements (Jan., 1993)

January, 1993 Measurement				
SETTLEMENT POINT	ELEVATION (Level Survey) H (m)	ELEVATION (GPS Survey) HI (m)	H-HI (m)	GDOP
YK8	3.928	3.928	0.000	
YK9	4.039	4.044	0.005	2
S55				
HT1	1.067	2.068	0.001	1
HT2	9.481	9.481	0.000	1
AN3	4.047	4.049	0.002	1
AN2	6.378	6.383	0.005	3
AN4	4.752	4.753	0.001	4
AN5	6.014	6.021	0.007	2
AN6	3.633	3.657	0.024	4
SP1	3.642	3.618	-0.024	3
SP2	4.258	4.235	-0.023	4
SP3	3.829	3.821	-0.008	3
SP4	3.723	3.741	0.018	5
SP6	3.961	3.977	0.016	3
SP7	4.506	4.505	-0.001	2
SP8				
SP9	1.249	1.263	0.014	2
SP10	1.616	1.630	0.014	2
SP27	0.327	0.325	-0.002	1
SP31	1.225	1.239	0.014	2
SP38	4.080	4.062	-0.018	1
SP43	1.425	1.443	0.018	2
SP53				
SP54	5.143	5.144	0.001	3
SP57	1.826	1.846	0.020	3
Average Error (m)			0.010	
Root-Mean-Square Error (m)			0.014	

Table 3. Comparisons between GPS and Level Survey Measurements (April, 1993)

April, 1993 Measurement				
SETTLEMENT POINT	ELEVATION (Level Survey) H (m)	ELEVATION (GPS Survey) HI (m)	H-HI (m)	GDOP
YK8	3.929	3.929	0.000	
YK9	4.039	4.039	0.000	2
S55				
HT1	2.067	2.067	0.000	1
HT2	9.476	9.476	0.000	
AN3	4.039	4.045	0.006	2
AN2	6.360	6.378	0.018	2
AN4	4.740	4.745	0.005	2
AN5	6.004	6.010	0.006	1
AN6	3.622	3.634	0.012	2
SP1	3.635	3.637	0.002	1
SP2				
SP3	3.817	3.824	0.007	1
SP4	3.712	3.733	0.021	2
SP6	3.953	3.979	0.026	2
SP7				
SP8				
SP9				
SP10	1.609	1.609	0.000	2
SP27				
SP31	1.221	1.240	0.025	1
SP38	4.072	4.081	0.009	2
SP43	1.420	1.464	0.044	2
SP53				
SP54	5.138	5.139	0.001	2
SP57	1.820	1.852	0.032	2
Average Error (m)			0.011	
Root-Mean-Square Error (m)			0.017	

geographic data designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (Dangermond, 1992).

In addition to the general features of GIS, this Ground Subsidence Information System was designed to satisfy two other major requirements: (1) all borehole information and monitoring results have to be incorporated in the system and which can effectively processed so that the fundamental subsidence mechanism can be understood and the analysis on future settlement can be conducted; and (2) images of land-cover and processed land-use map should be included in the system and which can easily be updated so that the government agencies can use this system to control the land use.

Details of this system is presented in Moh and Associates (1993). Data in Ground Subsidence Information System are organized as shown in Fig. 4. The major hardware used in this system is the INTERGRAPH Workstation InterPro 2730. The basic software used is the MGE System which is the platform and front-end setup for the Modular GIS Environment. Most of the other GIS applications are based on MicroStation 32, such as MGE Analyst, which can be added to MGE for classic GIS analysis capabilities.

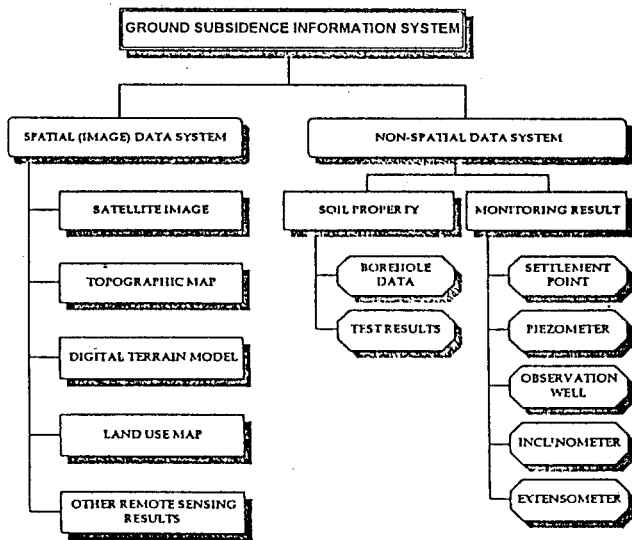


Figure 4. Data Structure of Ground Subsidence Information System

### APPLICATION OF SATELLITE IMAGES

Information on land-cover and land-use are very important to environmental planning and control in using Geographic Information Systems. Since earth resource satellite can provide relatively frequent data over large areas, it has increasingly become a major source of land-cover and land-use information. In Taiwan, Satellite Ground Receiving Station at the National Central University is now routinely receiving data from satellites Landsat and SPOT.

A significant amount of ground subsidence in very wide areas in Taiwan is caused by deep pumping from illegal fish farming. Government needs to use this Ground

Subsidence Information System to monitor the land use. Satellite images are very helpful in carrying out this task. But unless a reliable automated classification system can be implemented in this system, the advantages of using satellites images cannot be fully developed. Many classification algorithms have been developed since the launch of Landsat MSS and relatively reasonable results can be obtained (Lillesand and Kiefer, 1987). However, the statistical approach, commonly used by most of the traditional classification algorithms (Swain and Davis, 1978), is not designed to handle high spatial resolution satellite data, such as 20m resolution of SPOT which is used in this study.

This study introduces the use of neural network to perform land classification from SPOT images (Heemann and Khazenie, 1992). The neural network is the model that attempts to simulate the learning and recognition processes of the human brain. One of the most popular and most widely used neural network models is known as back-propagation (Chester, 1993). The topology of this type of network typically consists of three or more layers: an input layer, an output layer, and one or more hidden layers in between. Figure 5 illustrates a three-layer neural network. Each layer contains a number of nodes, which correspond to the human biological neurons. The input layer accepts input signals, and the output layer stores the results of the network. The hidden layer performs activation of the input signals and transfers the activation to the output layer through a nonlinear procedure. A complete processing of the neural network normally begins with pattern learning and ends with pattern recognition. The purpose of learning is to use training data to train the neural network to recognize a set of desired output patterns. As a result of the learning, the connection between layers will contain a set of weights which can be used to perform pattern recognition. After the neural network has been trained, the unknown input can be processed and recognized as proper pattern by the derived weights in the neural network.

In this study, the training data is represented by the brightness values of SPOT multispectral image and the desired output patterns are corresponding land-cover/land-use classes. SPOT images of 3rd October 1986 and 30th January 1988 were processed. Comparisons between the processed data can clearly identify the change of fishing farm areas. The results are in very good agreement with the change of the land use.

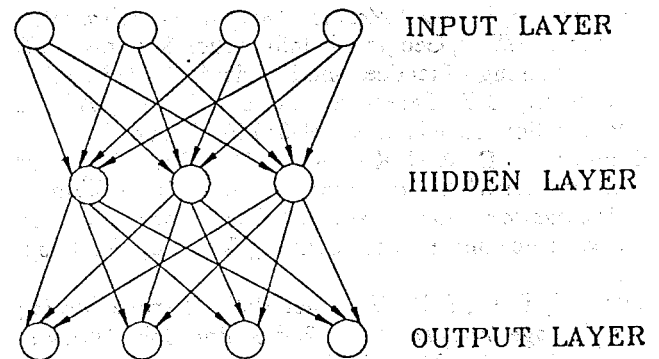


Figure 5. A Three Layer Neural Network

## CONCLUSIONS

Environment geotechnology is a relatively new field. Many of environmental geotechnical issue did not exist in the days of Terzaghi. It had not been included as a specialty session in the International Conference on Soil Mechanics and Foundation Engineering until the IXth Conference in Tokyo in 1975 (Moh, 1975). But now environmental geotechnical problems have become one of the most seriously concerned topics to geotechnical engineers. Today while many high-techs are making dramatic progresses, geotechnical engineers must be equipped with those advanced technologies to tackle those new environmental challenges. This paper briefly describes the application of satellite technology to ground subsidence problems. The successful result indicates that further applications of these techniques to other environmental geotechnical problems are very promising. More importantly, it exemplifies a situation that how a geotechnical engineer solve a problem with non-conventional tools - it may be quite frequently the case in the next century.

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