ROLE OF ARTIFICIAL INTELLIGENCE IN IDENTIFYING ENGINEERING EXPANSIVE SOILS USING SATELLITE IMAGERY AND AERIAL PHOTOGRAPHS

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ABSTRACT

Civil engineering structures should be constructed on stable soils. Therefore, it is essential to study the soil and to classify it according to its suitability for the intended civil engineering projects. In many cases small samples are taken from the sites and are tested in the laboratories. However, these samples are not faithful representatives for the whole area, particularly in case of large areas and for linear structures such as, roads.

The main objective of this research is to integrate data from aerial photographs, satellite imagery, and soil laboratories to develop an Intelligent Interactive Soil Data Base (I^2SDB). The I^2SDB system is intended for consultation purposes by civil engineers in primary investigations of engineering sites. The I^2SDB is specialized data base that has the ability to classify major types of soil. The system was tested and found to be practical and accurate. Conclusions obtained indicated proper behavior of the system and its competitiveness with similar results obtained by human experts.

1. INTRODUCTION AND MOTIVATION

In many parts of the world, civil engineering projects undergo collapsing, serious fractures, or similar unstable conditions. The reason for that is the type of soils that support the foundation of a structure. There are certain types of soil that can liftup or settle-down structures. These soils are known as expansive or shrinkage soils.

Most large civil engineering sites are investigated using laboratory tests. However, laboratory samples are not representative of the whole site, specially in long linear projects such as roads. Therefore, less expensive and more representative tools for site investigation should be developed. Aerial photographs and remote sensing images are candidate tools for site investigation. These two tools should be supported by laboratory tests. Aerial photographs and remote sensing, however, are tools that require professional experts to process advanced image interpretation. Experts, however, are rare and expensive and cannot participate in the planning stage of every giant civil engineering project.

The logical replacement of un-available expertise is to code the knowledge of the experts in a system that can be used by engineers for consultation purposes. Using Artificial Intelligent (A.I.) tools makes this coding possible. Expert systems are the suitable A.I. tool that can be used to efficiently program the expertise.

The main objective of this paper is to integrate remotely sensed data, field data, and aerial photographs to develop an Intelligent Interactive Soil Data Base (I^2SDB) that can participate in the planning stage of civil engineering projects. The I^2SDB is intended for identifying expansive soils and give suitable recommendations for civil engineers.

2. IMAGES AND EXPERT SYSTEMS

Aerial photographs are a sort of remote sensing product. Remote sensing can be described as an art, science, and tool of acquiring information about targets or certain phenomenon by a sensor that is not in contact with these targets or phenomenon (Cracknell, et al., 1993; Curran, 1985; Lillesand, et al., 1987). Accordingly, remote sensing is an acquisition tool, that can be used to investigate soils and other terrain parameters.

Interpretation process of space images is conducted according to systematic operations using low level and high level interpretation elements (Al-Garni, 1994; Carbone, et al., 1996). Key elements of interpretation contain an intelligent data-base of robust experience built throughout many years of experience in the minds of professional human interpreters. Terrain analysis techniques for image interpretation is a powerful tool (Al-garni, 1992 and Way, 1973; Mintzer, 1989).

A.I. is described as the study of how to make computers do things which at the moment people do better (Rich, et al., 1991). Expert systems are the applied portion of the A.I. science through which A.I. programs can code the experience of an expert in a field and transfer his experience to needed person (Bowerman, et al., 198; Hayes, et al., 1983).

3. SYSTEM DEVELOPMENT

Even though the total development of the I²SDB system is an increment process with overlapped phases, there are five ordered phases of developing the system explained as follows:

3.1 Identifying the Problem

Expansive soils can be identified using tools such as stereo-aerial photographs, satellite images, radar images, and laboratory testing of soils. However, very experienced group of people are required to conduct proper tests from the above list of sources. Accordingly, inexpensive tool that are able to guide a civil engineer should be available to help him conducting all tests by himself. This can be achieved through an intelligent knowledge base.

3.2 Data Acquisition

Real geographic location that contains soil problem must be selected for I²SDB. For this study, an area in Saudi Arabia called Tabouk that has soil problems was selected. Then all possible information that can be obtained about expansive and regular soils of Tabouk were acquired. This includes:

Maps from Ministry of Municipality and Rural Affairs (MOMRA), Control points from MOMRA, Aerial photographs from Military Survey Department (MSD), and Satellite images from King Abdulaziz City for Science and Technology (KACST).

3.3 Data Preparation

Very careful analysis and investigation of the soils was conducted. This was performed using manual and automatic techniques of interpretation. First, visual interpretation of stereo coverages of aerial photographs and maps was applied. Some visual factors or key elements of interpretation such as drainage, tone, and associations were extracted.

Second, satellite images for the area at different dates (1990 and 1993) were processed using proper image processing tools. Classification of soils, structures, and vegetation were conducted carefully. All these sets of data were prepared in suitable forms in order to code them in an object-oriented intelligent data base.

3.4 Data Presentation

Data presentation is an expression of building the structure of the intelligent data base. It is similar to regular data base structures, fields, and records. In object oriented expert systems there are classes, attributes, and instances. These three elements were the basic elements of structuring the knowledge base of I²SDB.

The search strategies used in developing the system were forward and backward search methods. To match the method of search that an expert has in mind while conducting image interpretation, the main method of search used in this project was backward chaining.

The primitive units of a class representation is a number of attributes and goals. The class was the landform and the attributes were topography, drainage, tone, gullies, vegetation, and laboratory tests (i.e. identification elements used in this research). Primitive facts are linked in conditional sentences by rules (IF-THEN-ELSE). The following is an example of typical rules in the system:
IF The Topography OF The Image IS Flat table rocks AND The Drainage OF The Image IS Angular dendritic AND The Tone OF The Image IS Light banded AND The Gullies OF The Image IS Few to none AND The Vegetation OF The Image IS Barren THEN The Landform : = "The Landform is Sandstone"

3.5 System Testing

The system passed through two phases of evaluation. The first phase was a debugging or editing phase. It started as soon as the knowledge engineer began to program the system and continued until the system was completed. The second testing phase was an evaluation process of system performance as compared to certain reference (e.g. human expert). This stage was conducted when the system was operational and ready be delivered to the end users.

4. SYSTEM IMPLEMENTATION

The major components of this system includes: input data, inference mechanism, user interface, output and feed back modules. Figure 1 shows these components.

The sets of input data were acquired by image interpretation. In this expert system one goal was assigned for identifying the expansive soil.

The task of the inference mechanism while conducting an application session may be viewed as intelligent tracking of a goal from a collection of classes, attributes and their method, rules, demons, displays and data bases.

Class allows the developer to reference and control the functions, flags, and current states of an application. The goals of an agenda contain attributes that can be linked to method, display, rule and conclusions.

4.1 Case Study For System Implementation

Tabouk was selected as a sample area in Saudi Arabia. It undergoes severe problems due to expansive soil (Al-jawhra, 1989). Tabouk soil is expanded as soon as it has some water content. Its drainage system is so poor. It is impervious soil. Due to poor permeability and due to existence of minerals that help expansion of soil in Tabouk, poor civil engineering locations must be identified. Accordingly, the problem in this research was defined as follows:
Tabouk contains expansive soils that require experts to define it in the real world and to inform people about its impact and poor suitability for civil engineering projects.

For this study, Tabouk area (Figure 2) was divided into 4 regions. Two of the regions were used to obtain data necessary for the development of the system (see Figure 3). The other two regions were used to test the system. The major concepts explained so far for developing the system were executed on the two regions assigned for the development. That is, problem identification, data acquisition and data presentation were conducted using the acquired information from the two regions of the case study area. Samples of collected, processed, and prepared data for system development are presented in Table 1.

Moreover, many images were processed for the study area. Sample of these images are seen in Figures 4 and 5. Also, laboratory tests of soil and field visits participated as important data for the development.

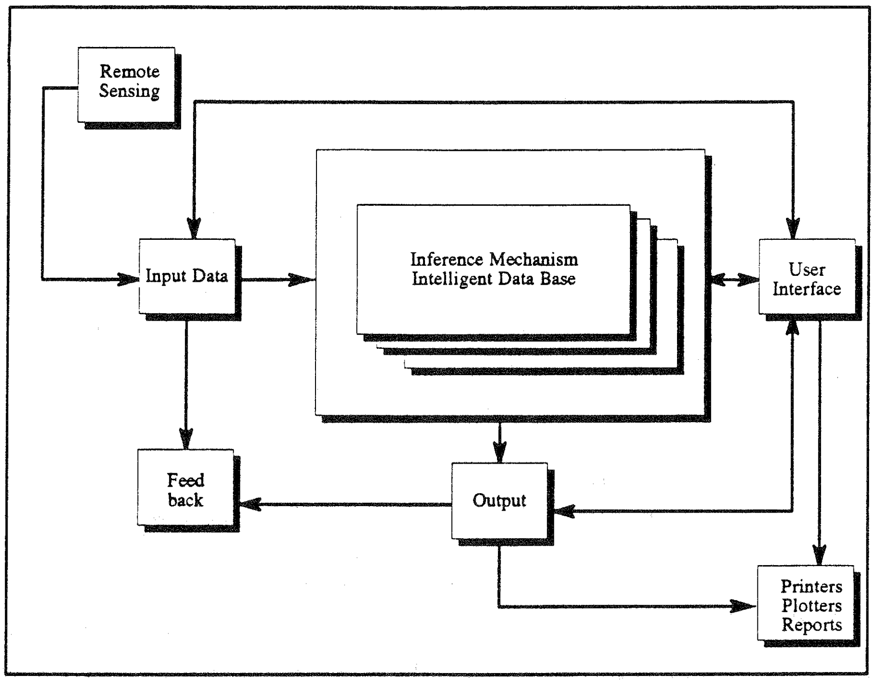

Figure 1: I²SDB Major Components.

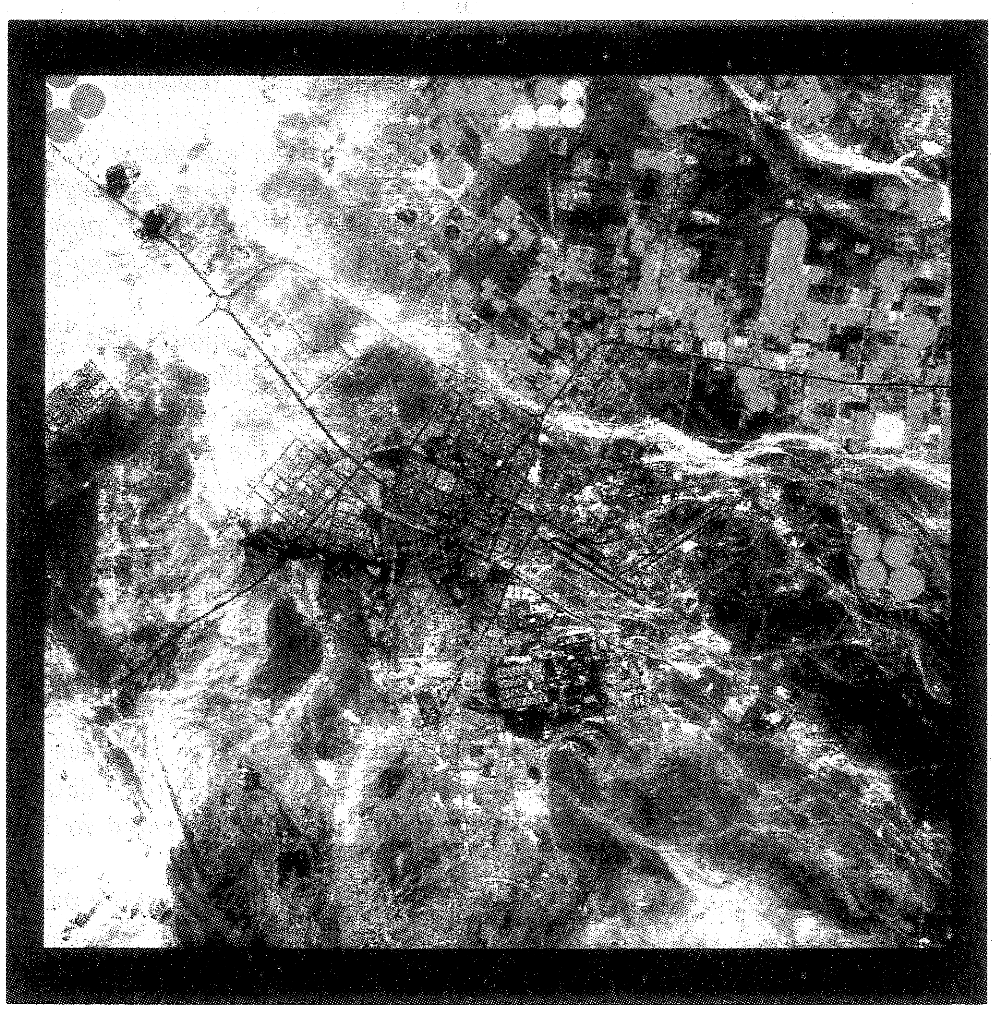

Figure 2: TM Image Showing The Study Area (Tabouk).

4.2 Acquiring and Preparing Data for I²SDB

4.2.1 Remotely Sensed Data: Landsat TM images were processed using image processing system as follows:

a. Two tapes containing the images of the study area for years 1990 and 1993 were acquired and have been used to achieve the aim of this study.
b. The extent (patches) of the study area was determined then down loaded to the hard disk.
c. Image enhancements such as histogram equalization were applied on the images in order to enhance the distinction between its features.
d. Preparing color composites were performed using standard bands of Red, Green, and Blue (RGB), respectively.
e. determining best band combinations to the to insure feature separability.
f. Performing classifications for selected band combinations using unsupervised modules and post-supervised classification techniques for (1990) and (1993) TM images.
g. Obtained data were prepared for coding them in the knowledge base of the system in a qualitative sense.

4.2.2 Laboratory Data: Field trips to the study area and collecting samples for laboratory testing were conducted. Two soil samples, from two different areas with two different characteristics were collected and brought to the environmental and soil laboratories at the civil engineering department at KSU.

Two major laboratory tests were performed. The first was the classification test for different soil types. The other test was a comprehensive test that last for about ten days. It covered all aspects of swell/shrinkage properties of the soil samples. It should be stated here that sample locations were defined on aerial photographs as well on the satellite images. Finally, these data were prepared carefully to be suitable for coding proper information in the knowledge base. The field data, also used as a real-world reference data for testing purposes as well as for verifying identities of unsupervised classes. Table 2 is a sample of laboratory soil tests.

5. DISCUSSION AND RESULTS

According to the findings of the laboratory test and image interpretation, soil was classified into clay, silt, and sand. Comparing these types in (A) and (B) sites showed that (A) contained high percentage clay, whereas it was less in (B). On the other hand, the soil swelling test showed that both areas were subjected to swelling. However, the swelling was higher in (A) than it was in (B) due to the existence of the mineral "montmorillonite" in site A. Montmorillonite is a mineral that cause soil swelling under certain weather conditions and with water availability. It should be stated here that the absence of montmorillonite does not necessarily mean the absence of swelling.

A correlation between swelling soils that were approved by lab tests and interpreted on TM images was verified. Accordingly, from interpreting images and re-entering its input to the I²SDB system soil swelling behaviors can be reported.

In case that soil is permanently dry, or permanently saturated, no soil swelling are expected in areas that contain factors causing swelling; that is stable weather condition prevents soil change.

I²SDB contains many recommendations each of which is a guidance for civil engineers on how to treat sites of projects according to the degree of the damaging behavior of bed soils. For instance, *having proper slopes to prevent still water from accumulating at or near structures, preparing very efficient draining systems to prevent water from reaching foundation soils of structures, and laying the structures on separate foundations on resistible soil with large factor of safety* are samples of recommendations contained in I²SDB in case of identifying expansive soils.

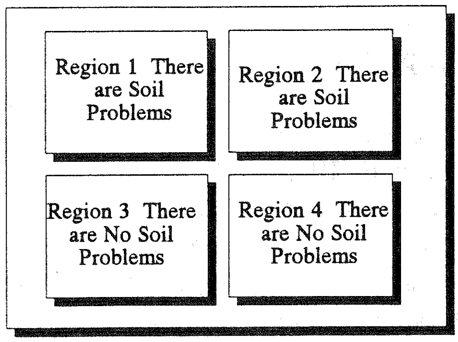

Figure 3: Major Divisions of The Study Area.

Table 1: Processing Region (1) of Tabuk Area with 5 Classes Using 1990 TM Images

Class No.	Color of Class	No. of Pixels	Percent of total %	Class Type
1	Green	2920	12.097	Vegetation
2	Black	4553	18.862	Pavement
3	Sand	6097	25.259	Soil A_1
4	Red	6947	28.780	Structure
5	white	3621	15.001	Soil A_2
Total		24138	100%	

Table 2: Results of Processing Four Real Investigations

Comparison	Results using the system	Results by human	Test No.
80%	Sand Stone	Silty Sand	1
70%	Shale	Silt	2
100%	Sand Stone	Sand Stone	3
75%	Shale	Silty Sand	4
95%	Sand Stone	Sandy Clay Silt	5
85%	$\frac{\Sigma\%}{No.\ of\ Test}$		Total

Figure 4: Enhanced Image of A Region in The Study Area for Visual Interpretation.

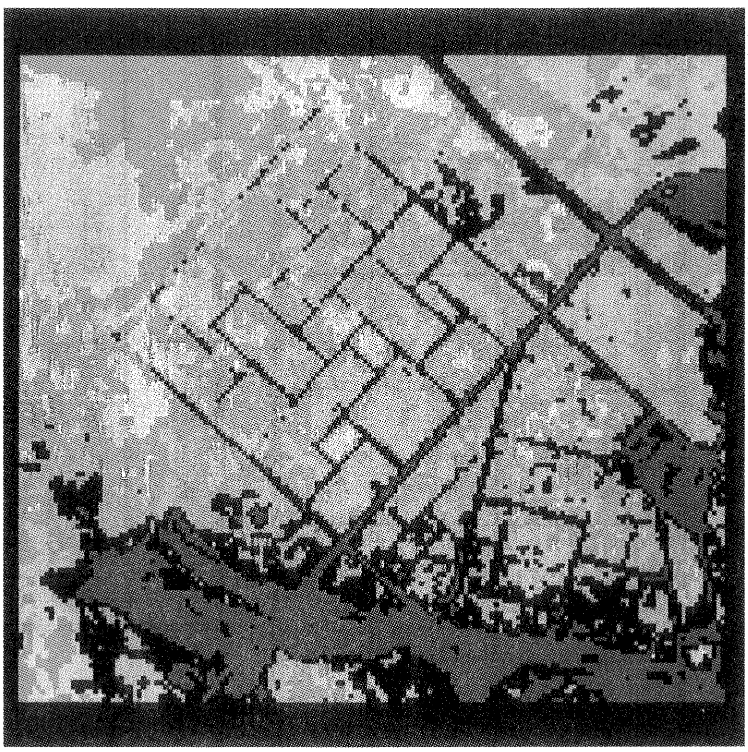

Figure 5: Sample of a Classified Region of The Study Area.

Table 3: Summary of Results of Soil Laboratory Tests

Sample No.	N.W.C. %	Specific gravity GS	Atterberg Limits %			Shrinkage Limit%	Grain Size Distribution				Type of Soil
			LL	PL	PI	SL	Grave 1 %	Sand %	Silt %	Clay %	
A	5.58	2.854	30.1	21.7	8.4	17.46	1.0	10.4	60.6	28.0	Sandy clay filt CL" clay with low plasticity
B	1.66	2.776	28.7	21.3	7.4	21.44	8.8	59.5	26.7	5.0	Brown silty sand

Water content determination
Wt. of can + wet soil = 68.26 Wt. of can + dry soil = 65.11 Wt. of can # 103 = 14.28 Wt. of water = 3.15 Wt. of dry soil = 50.83 Initial water content $_{w1}$ = 6.2%

Final water content determination # 5 = 146.00
Final water wt. + ring + dish = 384.84 Final dry wt. ring + dish = 360.70 Oven dry wt. of soil, w, 135.26 Final water content, to 17.87% Final degree of sat. S %

6. SYSTEM EVALUATION

Two tests were performed to validate the quality of the system. The first test was a debugging test that the knowledge engineer was performing during the whole stages of developing the system. The second test was an evaluation behavior of the system and its quality. This was accomplished by processing many consultation sessions on real problems. These sessions were performed by regular users. Then the same consultation session on the same area is performed manually either by: a) a human expert or b) knowledge engineer who has ground truth data bout the area of testing, without using the system.

The results of the two consultations (one by the system and another by a human expert) were compared. The results of four tests are presented in Table 3. System interpretation and human interpretation are compatible with an average confidence of 84%.

7. CONCLUSIONS

The developed small system is a powerful one that can be used for consultation purposes in expansive soils. It can be applied in similar region that have the same weather condition as that of Tabouk.

The system was tested and found to be accurate as a tool for shale and sandstone identification as primary locations for expansive soils. Aerial photographs and remote sensing play a great role in the identification process.

The system can be extended to have the provision of containing detailed design methods of different foundations. The designs should fit different cases based on different soil behavior, structure sizes, and weather conditions.

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