VSMM 2008
Digital Heritage – Proceedings of the 14th International Conference on Virtual Systems and Multimedia
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INTEGRATING SATELLITE REMOTE SENSING AND SPECTRO-RADIOMETRIC MEASUREMENTS FOR MONITORING ARCHAEOLOGICAL SITE LANDSCAPES

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KEY WORDS: satellite remote sensing, spectral signature, spectro-radiometric measurements, archaeology

ABSTRACT:

This paper explores the beneficial integration of both satellite remote sensing and in-situ spectroradiometric measurements for improving the available post-processing techniques in monitoring landscape changes in the vicinity of archaeological sites. The study has been conducted in the Kato Paphos archaeological area in the Paphos District area in Cyprus. Spectral signatures of different target areas have been measured in-situ using the GER1500 and SVC HR-1024 field spectro-radiometers. Classification and change-detection techniques have been applied for the available archived Landsat TM images and high-resolution Quickbird and IKONOS images.

1. INTRODUCTION

Archaeological studies have a long tradition of aerial photography application (Barnes, 2003). What has been changed in recent years about remote sensing application it is the development of new sensors (in particular multi-spectral Pavlidis *et al*., 2001; hyper-spectral such as Cavalli *et al*., 2003; microwave) and the availability of new tools for the management and integration of spatial information. Despite good archaeological results, there is a considerable reporting of the inherent limitations of this method of survey. The main problem is the cartographic nature of the data and the impossibility of planning the flights to coincide with “time windows” when conditions for the detection of archaeological features are at their best (Campana, 2007). Satellite remote sensing can provide a variety of useful data for monitoring and managing archaeological sites (Miller and Lee, 1991; Fowler, 2002; Hadjimitsis *et al*., 2005; 2006; 2007). Satellite image data provide a synoptic view which is not available from aerial photography. It takes over 200 aerial mapping photos to cover the same area as a single satellite image.

The importance of applying space technology to cultural heritage and archaeological research has been paid great attention worldwide, mainly because very high resolution (VHR) satellite data such as, IKONOS (1999) and QuickBird (2001), are able to match with aerial photogrammetric images (Lasaponara and Masini, 2005).

The extent of the problem of the changing landscape nearby the archaeological sites is mostly unknown, however, and efficient coping strategies are not developed. In this paper we present an overview of the basics of the application of remote sensing in such tasks. Indeed, change detection method based on the use of the Normalized Difference Vegetation Index (NDVI), classification, image-overlay applied to Landsat TM images with different acquisition dates, followed by image subtraction (differencing) have been also presented. This procedure results in an easily interpretable and extremely quick approach to change detection of land cover as well as change in biomass, and it can be used as a ‘first warning’ method to indicate archaeological sites threatened by the nearby changing landscape.

2. REMOTE SENSING

2.1 Introduction

Remote sensing covers all techniques related to the analysis and use of data from environmental and earth resources satellites and from aerial photographs. Remote Sensing is the science of deriving information about an object from measurements made at a distance from the object (i.e. without actually coming in contact with it).

With their continuous development and improvement, and free from national access restrictions, satellite sensors are increasingly replacing surface and airborne data gathering techniques. At any one point in time, day or night, multiple satellites are rapidly scanning and measuring the earth’s surface and atmosphere, adding to an ever-expanding range of geographic and geophysical data available to help us manage and solve the problems of our human and physical environments. Remote Sensing is the science of extracting information from such images.

Landsat TM and MSS, SPOT satellite images are widely used for deriving information about the earth’s land. Moreover, the operational availability of high-resolution satellite imagery, (i.e. Quickbird, IKONOS), opens up new possibilities for investigating and monitoring natural resources. Compared with traditional survey techniques, satellite remote sensing is

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accurate, timely and cost-effective. These data offer a number of advantages:

- Provide synoptic coverage and therefore give an extensive view of vast areas at the same time.
- Images can be acquired for the same area at a high rate of repetition (two to three times a month), thus permitting selection of the most appropriate seasonal data.
- Satellite images are recorded in various wavelengths, visible and non-visible, which provide accurate information on ground conditions.
- They can be obtained for any part of the world without encountering administrative restrictions.

2.2 Fundamentals of Remote Sensing

The Sun has a temperature of about 5800 degrees Kelvin, and emits electromagnetic radiation from about 0.5-4.0 micrometers (Mather, 2001; Richards, 2005). This radiation is filtered by the Earth's atmosphere, which absorbs energy in a series of bands related to the chemistry of the atmosphere. Energy reaching the surface of the earth is reflected - the amount of energy reflected in each wavelength is a function of the surface characteristics, so that in principle different types of surface can be identified from their spectral reflectance characteristics, since these differ significantly from material to material (see Figure 3). Some energy is absorbed by the Earth, which because it has a lower temperature than the Sun is re-emitted at higher wavelengths (typically between thermal infrared wavelength region i.e. 8-12 micrometers with maximum intensity at 10 micrometers). Hotter objects on the Earth's surface emit significantly more radiation at these 'thermal' wavelengths.

Energy leaving the Earth's surface must travel once again though the atmosphere before reaching a satellite sensor. Atmospheric effects can significantly modify the radiation (an obvious effect can be seen when cloud cover is present), by absorbing and attenuating it differentially in the various wavelengths of interest, and by adding to it as a result of energy scattered within the atmosphere and then radiated towards the satellite. Atmospheric effects vary spatially and with time, as a result of changes in atmospheric moisture and pollution.

Satellite remote sensing systems essentially consist of a platform (the satellite) upon which is mounted a camera or a series of cameras. Electromagnetic radiation (visible light and infrared radiation) is filtered as it arrives at the satellite, with different wavelengths being sent to different detectors. Because of the absorption of the atmosphere little energy arrives at certain wavelengths, and so detection is normally restricted to a limited number of bands, which detect energy in the atmospheric 'windows'. Most satellite sensors will detect in a limited number of bands, and many fewer than will be used on an airborne multi-spectral sensor.

The filtered electromagnetic energy is passed to sensors that detect its intensity, and convert it to a digital number (DN). The sensor captures energy for a series of small areas of the ground ('picture elements', or pixels) that it images.

Multi-spectral satellite data consist not of 'images' in the commonly-accepted sense of the term, but a number of matrices, each cell within a given matrix representing the intensity of the electromagnetic energy received in a particular wave band from a given pixel, or small area of the ground. These data must be manipulated mathematically before an image can be produced, perhaps being projected on a computer screen or printed. A number of stages of processing may be carried out before the results are presented to the end user. These are:

- geometric correction, to align the image with some ground control system (e.g. latitude and longitude, or some national grid reference system
- atmospheric correction to recover, as far as possible, the reflectance at the ground surface
- processing, either to extract the most from the data (e.g. edge detection to identify boundaries) or to classify pixel values as far as possible in terms of the ground conditions
- Presentation of data, typically involving the assignment of computed data (following stretching) to the three primary CRT colours (red, green, blue) for display purposes, or the assignment of land classes to different colours in order to produce a thematic map.

3. SPECTRAL SIGNATURES

Features on the Earth reflect, absorb, transmit, and emit electromagnetic energy from the sun. Special digital sensors such as spectro-radiometers have been developed to measure all types of electromagnetic energy as it interacts with objects in all of the ways listed above. The ability of sensors to measure these interactions allows us to use remote sensing to measure features and changes on the Earth and in our atmosphere.

A measurement of energy commonly used in remote sensing of the Earth is reflected energy (e.g., visible light, near-infrared, etc.) coming from land and water surfaces or other targets. The amount of energy reflected from these surfaces is usually expressed as a percentage of the amount of energy striking the objects. Reflectance is 100% if all of the light striking and object bounces off and is detected by the sensor. If none of the light returns from the surface, reflectance is said to be 0%. In most cases, the reflectance value of each object for each area of the electromagnetic spectrum is somewhere between these two extremes.

Across any range of wavelengths, the percent reflectance values for landscape features such as water, sand, roads, forests, etc. can be plotted and compared. Such plots are called “spectral response curves” or “spectral signatures.” (See Figures 4, 5) Differences among spectral signatures are used to help classify remotely sensed images into classes of landscape features since the spectral signatures of like features have similar shapes.

Knowledge of the spectral characteristics of the materials to be classified when imaging cultural heritage sites is essential if robust image processing techniques are to be identified or developed. Spectral analyses of digital data are normally carried out using one of the following:

- 'standard' analyses, such as the 'tasselled cap' (Crist and Cicone, 1984) or NVDI methods, that produce images processed to enhance certain ground characteristics (e.g. vegetation cover), but must be interpreted subjectively
- Classification techniques that aim to identify ground characteristics.

Classification can be 'unsupervised', dividing the ground cover into a predetermined number of classes on the basis of its spectral characteristics alone, or 'classified', using knowledge of ground cover at various positions on the particular image or images ('ground truth'), or using reflectance data obtained from spectro-radiometers such as those shown in Figures 3, 4 and 5. Both have their place in archaeology.

4. CHANGE DETECTION TECHNIQUES

Change detection has become a major application of remotely sensed data because of repetitive coverage at short intervals and consistent image quality. The basic premise in using remote sensing data for change detection is that changes in land cover result in changes in radiance values and changes in radiance due to land cover change are large with respect to radiance changes caused by others factors such as differences in atmospheric conditions, differences in soil moisture and differences in sun angles. Several change detection techniques applied to satellite digital images along with GIS techniques have been reported in the literature. Some of these include image overlay, image difference, ratioing, principal component analysis (PCA), and post-classification etc. An important component to change detection is radiometric calibration including atmospheric correction.

4.1 Image Overlay

The simplest way to produce a change image is by making a photographic two-colour composite (of a single band) showing the two dates in separate colour overlays. The colours in the resulting image indicate changes in reflectance values between the two dates. Thus, features that are bright (high reflectance) on date 1, but dark (low reflectance) on date 2, will appear in the colour of the first photographic overlay. Features, which are dark on date 1 and bright on date 2, will appear in the colour of the second overlay. Features, which are unchanged between the two dates, will be equally bright in both overlays and hence will appear as the colour sum of the two overlays (Mather, 2001)

4.2 NDVI

Many techniques have been developed to study quantitatively and qualitatively the status of the vegetation from satellite images. To reduce the number of parameters present in multispectral measurements to one unique parameter, the Vegetation Indexes were developed. Vegetation Indexes are combinations of spectral channels, in such a way that it reflects the contribution of vegetation depending on the spectral response of an area, minimizing the contribution of other factors such as soil, lighting, atmosphere, etc. (Richards, 2005). The Normalized Difference Vegetation Index (NDVI) is a nonlinear function which varies between -1 and +1 but is undefined when RED and NIR are zero. Only the positive values correspond with vegetated zones. The negative values, generated by a higher reflectance in the visible region than in the infrared region, are due to clouds, snow, bare soil and rock

4.3 Basics of classification

Objects of similar natures have similar spectral properties. That means that the electromagnetic radiation reflected by objects or targets of the same nature is similar overall and these objects will thus have similar spectral signatures. Since the spectral signatures of the objects observed by satellite sensors are converted into different colours in digital images, objects of the same kind will appear in closely related colours. This property has been widely used for many years to interpret aerial photographs and the images supplied by Earth-observing satellite sensors. The interpreter places in the same category all the objects in an image that seem to have the same or closely related colour. Based on the fact that the colours in a digital image are merely a conventional transposition of numerical values, it is also possible to exploit the computer’s computational power to classify the pixels by their numerical values, which is to say, in the final analysis, by the corresponding objects’ spectral properties (Janssen *et al*., 1990). This is the basic principle of image classification. Basically there are two types of classification, the unsupervised and supervised classification:-

In unsupervised classification, the computer is allowed to analyse all of the spectral signatures of all of the image’s pixels and to determine their natural groupings, that is to say, to group the pixels on the basis of their similar spectral signatures (Richards, 2005). The main advantage of this method is its great speed, for it requires practically no intervention from the user.

Supervised Classification is a procedure for identifying spectrally similar areas on an image by identifying ‘training’ sites of known targets and then extrapolating those spectral signatures to other areas of unknown targets (Richards, 2005). Supervised classification relies on the *a priori* knowledge of the location and identity of land cover types that are in the image. This can be achieved through field work, study of aerial photographs or other independent sources of information.

Remote sensing can be a discovery technique, since the computer can be programmed to look for distinctive "signatures" of energy emitted by a known site or feature in areas where surveys have not been conducted. Such "signatures" serve as recognition features or fingerprints. Such characteristics as elevation, distance from water, distance between sites or cities, corridors, and transportation routes can help to predict the location of potential archeological sites

Since sand, cultivated soil, vegetation, and all kinds of rocks each have distinctive temperatures and emit heat at different rates, sensors can "see" things beyond ordinary vision or cameras. Differences in soil texture are revealed by fractional temperature variations. So it is possible to identify loose soil that had been prehistoric agricultural fields, or was covering buried remains. The Maya causeway was detected through emissions of infrared radiation at a different wavelength from surrounding vegetation. More advanced versions of such multi-spectral scanners (Visible & IR) can detect irrigation ditches filled with sediment because they hold more moisture and thus have a temperature different from other soil. The ground above a buried stone wall, for instance, may be a touch hotter than the surrounding terrain because the stone absorbs more heat. Radar can penetrate darkness, cloud cover, thick jungle canopies, and even the ground.

4.4 Image Differencing

Another procedure is to register simply two images and prepare a temporal difference image by subtracting corresponding pixel values for one date from those of the other. The difference in the areas of no change will be very small, and areas of change will reveal larger positive or negative value. In this method, registered images acquired at different times are subtracted to produce a residual image, which represents the change between the two dates. Pixels of no radiance change are distributed around the mean, while pixels of radiance change are distributed in the tails of the distribution.

5. METHODS AND MATERIALS

The post-processing techniques for visualise the land-cover changes in the nearby landscape of the archaeological sites have been applied to both Landsat TM and high-resolution images such as Quickbird and IKONOS. Then, based on the acquired in-situ spectro-radiometric measurements, NDVI and classification techniques have been applied to compare directly the % of identification and extraction of the archaeological sites (image extraction Vs in-situ).

5.1 Images

Archived Landsat-5 TM images of the Paphos District area in Cyprus acquired on the 30/01/2001, 11/5/2000, 11/9/98 and 3/6/1985 have been used (Figure 1). Ikonos (Figure 6) and Quickbird image acquired on 14/3/ 2000 and 23/1/2003 respectively was also used to track more easily the spectral targets (Figure 2). The District areas of Paphos and Limassol which consist many cultural heritage sites have been selected to be used as pilot studies.

Figure 1: Quickbird- 0.6m resolution image of Paphos harbour area acquired on 23-12-2003 (castle and House of Dionyssos area)

5.2 Ground Measurements

The Remote Sensing and Geodesy Laboratory of the Department of Civil Eng. and Geomatics at the Cyprus University of Technology support the ground measurements of this project. Indeed, Two GER1500 field spectro-radiometers and the SCV HR-1024 have been used to retrieve the amount of atmospheric effects in different targets in the vicinity of cultural heritage sites (see Figures 2, 3, 4 and 5).

Figure 2: Collection of spectral signature data on a whitish bare soil using the GER1500 Field Spectroradiometer

Figure 3: SCV HR-1024 Field Spectroradiometer

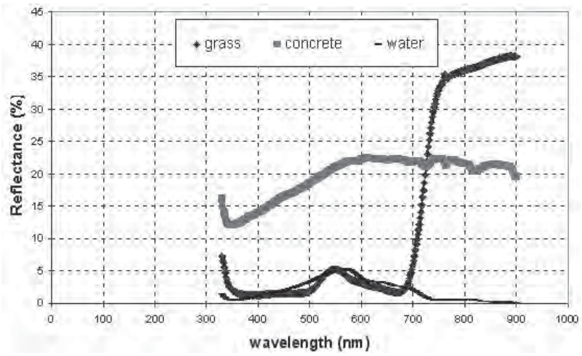

Figure 4: Spectral signatures of three different materials: grass, concrete, water obtained using a GER1500 field spectro-radiometer

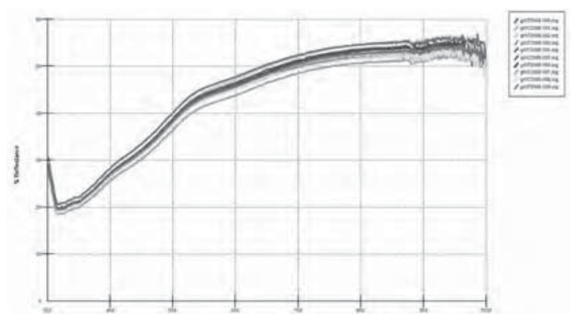

Figure 5: Spectral signatures of bare soil (whitish colour) obtained using a GER1500 field spectro-radiometer on the 20/7/2008 in Paphos District area.

Figure 6: Unsupervised classified-5 classes IKONOS pan-sharpened 1m high-resolution satellite image of Katos Paphos archaeological site acquired on 14th of March 2000.

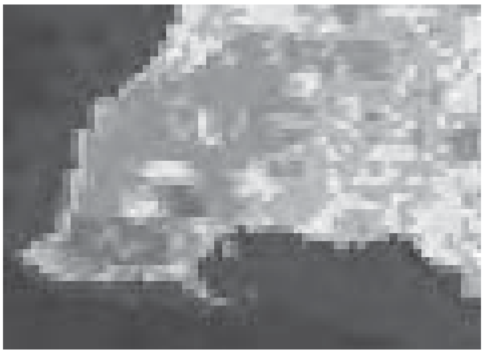

Figure 7: Unsupervised classified (7-classes) Landsat TM image of Katos Paphos archaeological site acquired on June 1985.

5.3 Application of atmospheric correction

The darkest pixel (DP) atmospheric correction method, also termed also histogram minimum method was applied to the multi-series satellite images of Cyprus area since it has been found that is the most effective atmospheric correction algorithm (Hadjimitsis *et al*., 2003).

5.4 Extraction

Further to the application of the change detection algorithms, the processing was carried out using Principle Component Analysis (PCA) (see Figure 8), Tasseled Cap Transformation (TCT), Decorrelation Stretch (DS) and RGB colour composites (Mather, 2001) for site extraction.

Figure 8: Principal Component Analysis: Quickbird- 0.6m resolution image of Kato Paphos Paphos archaeological area acquired on 23-12-2003

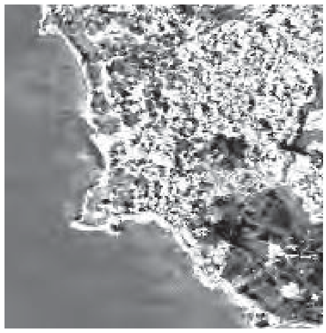

Figure 9: Image-Subtraction of Landsat TM images: 2000-1985

6. RESULTS

On completion of the image processing as expected the best results come from transformations in which the near infrared band plays a primary role, especially in NDVI, Principal Component Analysis, brightness and Wetness Transformation and relative colour composites. In our study we concluded that bands green, red and near infrared, show the most potential for the identification of archaeological features. Red and near infrared images are less affected by haze and provide good definition for soil marks and crop marks. Despite these promising early results the true potential of this type of imagery is still not fully clear and needs to be further evaluated to test its responsiveness under a broad range of environmental conditions.

By applying the change detection techniques, it has been found that in the nearby area of the Kato Paphos archaeological site area, a 20 % difference in the landscape has been occurred (Figure 9). Indeed by comparing the results obtained between supervised and unsupervised classification results for the high-resolution satellite images based on the use of the in-situ spectral signatures, it has been found that in the green and red bands the difference between the two methods on the % measured land in each class was 10 %.

7. CONCLUSIONS

It has been shown that the integration of both post-processing techniques with the in-situ spectroradiometric measurements can improve the effectiveness of such methods especially for monitoring landscape changes in the vicinity of archeological sites. We concluded that bands green, red and near infrared, show the most potential for the identification of archaeological features. By applying the change detection techniques, it has been found that in the nearby area of the Kato Paphos archaeological site area, a 20 % difference in the landscape has been occurred. Future work consists of further validation and assessment of every post-processing algorithm for such task in conjunction with simultaneous measurements of the following: image overpass, spectral signature measurement and atmospheric conditions measurements.

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9. ACKNOWLEDGEMENTS

The authors acknowledge the support of the Remote Sensing Laboratory and Geodesy Laboratory of the Department of Civil Engineering and Geomatics at the Cyprus University of Technology for providing the GER1500 and SVC HR-1024 field spectro-radiometers (http://www.cut.ac.cy/ce/)