World Transactions on Engineering and Technology Education
Vol.11, No.3, 2013

Investigating the advantages of satellite data as evidence in possible litigation

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ABSTRACT: A reliable, fast and economical method for longitudinal recording of land use changes based on satellite remote sensing is studied. It measures temporal land-use changes that have occurred within specific area of the Manesi community in the Argolida region of Greece. The analysis is based on the usage of diachronic satellite imagery derived from Landsat data from 1984 to 2005. The analysis of the satellite images was combined with fieldwork, using GPS devices on control surfaces. A specific land-use development located in the study area is a point of dispute between two opposing groups. The purpose of this study is to identify the advantages of satellite data as evidence in possible litigation, where the engineers, as invited experts, are looking at reliable data to prove environmental or human-made changes on the land-cover or the land-use. The temporal land use in the study area was compared with the corresponding land use in the selected control area. The results showed that in the study area, the land had never been cultivated and trees were never planted during the period from 1984-2007 in contrast with the defendant's contention.

INTRODUCTION

Over time, there are many changes in land use of a site and consequently the natural environment. These changes are due to two main factors, which are natural disasters (e.g. fire, floods, etc) and anthropogenic interventions (e.g. the extension of farmland, deforestations, etc). Remote sensing techniques are commonly utilised, in order to survey those changes and collect information that can aid the process of decision making. This process is usually referred to as *change detection*, and is been applied on various data sets that have been derived from a variety of sensors, such as airborne and space-born cameras, Radar, Lidar, etc.

There are several well-established remote sensing techniques, such as colour composite interpretation, classification, simple and complex ratios, etc, which are capable of highlighting areas with specific characteristics upon the imagery. Most techniques that are applied to hyper-spectral imagery are based on the fact that different objects reflect the sunlight in a different way throughout the electromagnetic spectrum and by analysing this reflectance *behaviour*, one can extract useful information, e.g. type of land cover or land usage, etc [1].

In this study, the remote sensing technique of histogram analysis (histogram method) was applied over 11 medium-resolution, temporal satellite data sets (Landsat TM), that were first converted by the application of the NDVI complex ratio. The aim was to determine the territorial coverage of the area of study over a long period of time (particularly from 1984 to 2007), in order to draw conclusions about a certain claim whether the area had been under agricultural cultivation or not during that period.

By utilising the spectral signatures, which were recorded in the near-infrared part of the electromagnetic spectrum upon NDVI ratio imagery, a temporal hyper-spectral profile of the area of study was created, which was compared with the profile of a specific control area covered by natural vegetation. This hyper-spectral profile was determined by examining Channel 4 (NIR) of the Landsat TM imagery, due to the fact that natural vegetation tends to maximise its reflectability in that specific area of the electromagnetic spectrum and, thus, being significantly higher than the reflectability of bare earth and naked soil. The control area was surveyed in the field with a GPS device in order to determine its boundary polygon. Similar temporal hyper-spectral profiles of the study area and the control area would lead to the conclusion that the area of study was indeed under agricultural cultivation, and different profiles would lead to the conclusion that the area had a different land coverage (e.g. naked soil).

The software used in this study was PCI Geomatica Suite for applying all remote sensing techniques, as well as for pre-processing and processing the imagery, and ESRI ArcGIS for ancillary usage and the map composition of the Corine Land-cover digital data set.

DATA SETS AND METHODOLOGY

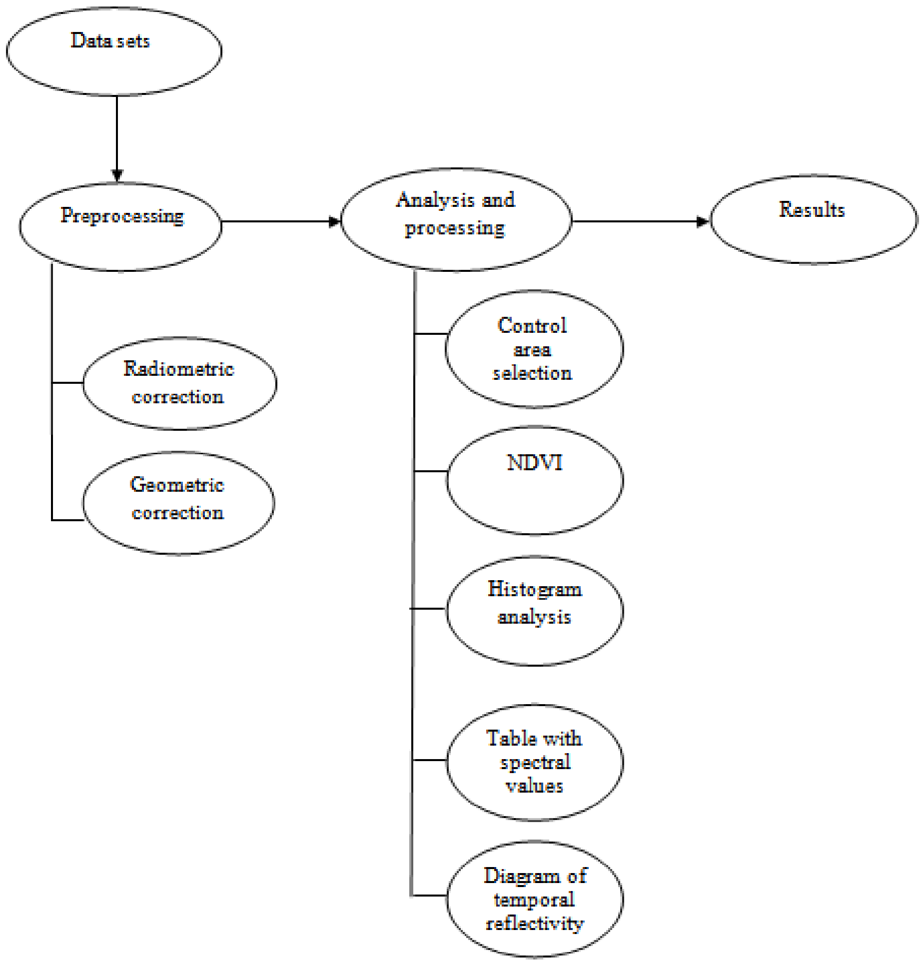
In this study, in order to extract relevant information about the temporal land use of the study area, three temporal Landsat TM 4, and eight Landsat TM 5 satellite hyper-spectral imagery, holding a spatial resolution of 30 m and dated from 1984 to 2005 were used [2]. For the purposes of supplementary photointerpretation, in order to cross check the results, an IKONOS image was utilised, with a spatial resolution of 1 m and date of capture 14 April 2007 and a Quickbird image, with a spatial resolution of 2.62 m and date of capture 14 April 2007. These satellite imagery data sets were available at the Laboratory of Agricultural Constructions of Agricultural University of Athens (AUA), which significantly reduced the cost of the study, and their selection was based upon the month and the year of imagery capture.

The choice of the imagery time capture aimed to keep the effect of the sunray angle of incidence as small as possible, and in that way to reduce the phenomena of dark surfaces on the imagery caused by shadows coming from the relief variations. Ancillary data sets were used in the study, which consisted of a series of topo maps scaled 1:50,000 and derived from the Hellenic Military Geographical Service (HMGS), as well as a digital map of Corine Land-cover 2000, which was composed in a GIS environment by data derived from the EU.

The methodology followed in this study consisted of a combination of remote sensing techniques, in order to draw conclusions on the changes of uses and land cover in the area of study. The imagery derived from the satellite sensors were the primary data for processing and analysis. In the pre-processing stage, the hyper-spectral data set was submitted to a process of atmospheric and radiometric correction in order to compensate for the different sun illumination conditions over the different period of imagery capture.

Concluding the pre-processing stage, an image geometric correction was applied, based on the second-degree polynomial mathematical model, in order to register the original images from the system of lines and columns (rows-columns) of the linear scanner in the cartographic projection of the geodetic reference system used (in this case, a Transverse Mercator projection of GGRS 87 datum) [3]. The analysis and processing stage followed, where the control area was chosen on the basis of a set of criteria and the pre-processed satellite images were converted to NDVI ratios and histogram analysis applied to them. Finally, in the stage of the conclusion extraction, the results of the applied methods were determined.

Figure 1: Methodology workflow.



REPROCESSING

The image radiometric correction is accomplished by converting DN values of TM sensors into radiance and reflectance values. This is achieved by using detector calibration tables prepared for each sensor. This method uses the Radiance program on the Geomatica image analysis system, and takes into account a set of gain and offset values found in these tables. The process requires no ancillary data information apart from those relevant calibration tables distributed by NASA. Therefore, brightness values for each TM band are first converted to radiance ($mW m^{-2} sr^{-1} \mu m^{-1}$), using Equation (1) and, then, to reflectance values using Equation (2) [4]:

$$RAD_i(x,y)=[DN_i(x,y)-OFFSET_i]/GAIN_i \quad (1)$$

$$REF_i(x,y)=RAD_i(x,y)/S.E.I \quad (2)$$

Where:

$RAD_i(x,y)$ = radiance value at pixel (x,y) in band i;
$DN_i(x,y)$ = output digital number for band i at pixel (x,y);
$GAIN_i$ = gain factor used for band i;
$OFFSET_i$ = offset factor used for band i
$REF_i(x,y)$ = reflectance value at pixels (x,y) in band i;
S.E.I = solar exoatmospheric irradiance ($mW m^{-2} sr^{-1} \mu m^{-1}$).

The image geometric correction (registration) was achieved by using ground control points (GCPs), which were extracted from the georeferenced topo maps. Measuring 10 GCPs on every image, while six is the minimum number for geometric correction with the mathematical model of second degree polynomial equations (Equation (3) and Equation (4)), provided the model with extra observations, in order to accurately determine the values of the polynomial equation coefficients (a1, a2, a3, a4, a5, a6, b1, b2, b3, b4, b5, b6) through a process of mathematical adjustment. These polynomial equations carry the transformation of the image pixels from one reference system to another. With evenly distributed GCPs across the image geometric correction achieved a total RMSE of less than 1 pixel [1].

$$x = a_1 + a_2 X + a_3 Y + a_4 X Y + a_5 X^2 + a_6 Y^2 \quad (3)$$

$$y = b_1 + b_2 X + b_3 Y + b_4 X Y + b_5 X^2 + b_6 Y^2 \quad (4)$$

where x, y are the image point's coordinates and X, Y are the coordinates of the corresponding point on the geographic system used.

ANALYSIS AND PROCESSING

In order to compare the spectral behaviour of the area of study by histogram analysis over NDVI ratio, it was necessary to have a control area. This control area was chosen on the basis of a set of criteria and, then, its boundaries were surveyed on the field using handheld GPS device. The criteria were:

- Access by foot in order to be surveyed.
- Constant land coverage by the same type of natural vegetation, in order not to have a mixed hyper-spectral behaviour.
- Constant land coverage throughout the year, because the imagery temporal data set were captured at different times and in different seasons of the year.
- Land coverage consisted of sclerophyllous vegetation because this type does not show phenotypic changes during seasonal changes and, therefore, has a non-changeable hyper-spectral behaviour. Moreover, the particular type of vegetation is encountered at low altitudes, which contributes to the accessibility of the area and is low height vegetation, so the GPS signal for the survey would not be interrupted.
- Proper area size, in order for its polygon boundaries to be overlayed on the 30 m pixel size Landsat imagery and still be discrete for the analysis.

Processing the imagery in order to apply the histogram analysis comparison, an NDVI complex ratio was calculated over each satellite image. The precise ratio was specifically designed by NASA for Landsat TM image interpretations that were about vegetation studies. The NDVI formula (4-3)/(4+3) is applied by dividing the difference of the values recorded on Channels 4 and 3, with the summary of the values on the same channels. This mathematical calculation leads to a new image with normalised pixel values from 0 to 1, and these highlight the areas with healthy vegetation on the image. This formula is based on the fact that the reflectance of the vegetation is as significantly high in Channel 4, as it is low in Channel 3. In that way, NDVI imagery 0 value represents no vegetation, though value 1 stands for full healthy vegetation [5]. Using normalised values enhances the comparability of different images by eliminating differences in the imagery caused by the different hour, different season of the year, etc.

The polygons of the study area and the polygon of the control area were overlaid with the NDVI imagery in order to apply the histogram analysis. This specific remote sensing technique is conducted by extracting the pixel values from under each polygon and calculating their mean value on every image.

A higher mean pixel value under an area on the NDVI imagery would mean that the area is covered by vegetation, though lower mean values would mean that vegetation was not present. The exported mean pixel values for the control area and the study area are shown in Table 1. By reporting those values over the estimation period of 1984 to 2005, the temporal spectral profiles (Figure 2) of both areas are being created and can, then, being submitted for comparison.

Table 1: Mean pixel values on the NDVI complex ratio imagery.

Capture date	Study area	Control area
04-08-1984	0,15	0,24
19-05-1985	0,33	0,57
10-06-1987	0,08	0,40
26-06-1987	0,04	0,48
08-06-1990	0,07	0,25
21-06-1991	0,38	0,48
16-08-1991	0,21	0,27
26-08-1992	0,32	0,41
25-08-2003	0,04	0,37
10-01-2005	0,35	0,44
20-05-2005	0,12	0,20

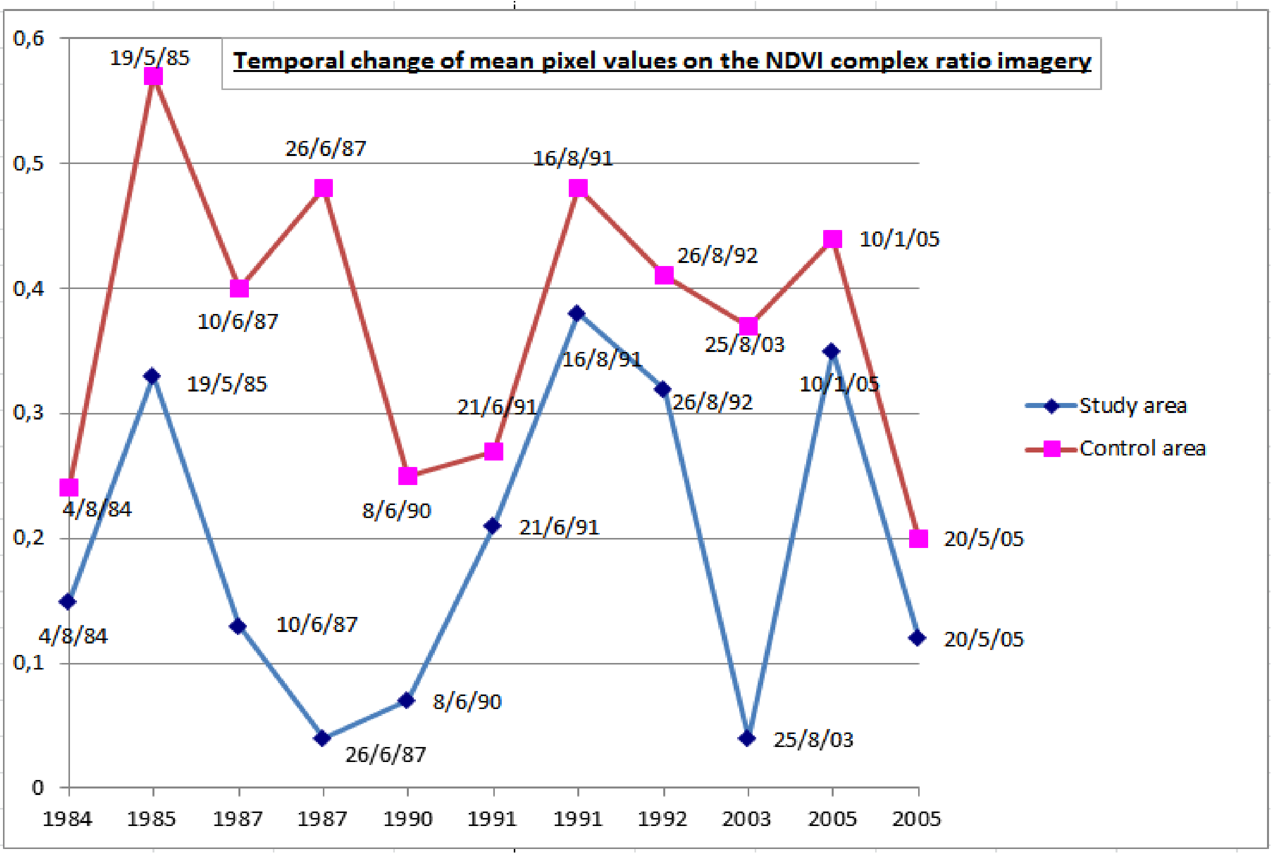


Figure 2: Temporal hyper-spectral profile for the study and control area.

RESULTS

In the final stage, conclusions were formed based on the results of the histogram analysis. By examining the temporal spectral profile for both the area of study and the control area, one can observe that the control area shows higher mean pixel values derived from the NDVI imagery, throughout the study period of 1984 to 2005. This leads to the safe conclusion that within the specific period, those two areas did not present the same type of land coverage. Given the known land cover of the control area, which was selected to be natural sclerophyllous vegetation, it is easy to conclude that between 1984 and 2005 the study areas had never been cultivated for a period of time, due to the fact that it did not appear that there was any vegetation coverage.

To crosscheck the results, a set of colour composites was created with the high resolution Ikonos and Quickbird satellite imagery. By utilising triplet combinations of the imagery bands involving Channel 4 (on which the higher reflection values of the natural vegetation are observed) and, specifically, the 4-3-1 and 5-4-3 colour composite, the study area polygon was overlaid and an optical photo interpretation performed.

On the 4-3-1 colour composite the cultivated areas appear in intense red colour and on the 5-4-3 composite with intense green colour. On neither of these composites was the study area observed as appearing with the same colour as the rest cultivated areas, which verifies the histogram analysis result, that the study area was never under cultivation during the 1984-2005 period. The results showed that in the study area, the land had never been cultivated and trees were never planted in the period from 1984-2007 in contrast with the contention of the defendant side.

CONCLUSIONS

Digital remote sensing is a new technology currently used in environmental management, surveying, resource researching and many more. Natural environment, as well as rural environment, is placed among the renewable natural resources that can be affected by a range of social and economic changes. Temporal monitoring of these changes can provide important information and can deliver several advantages in determining future actions. The conclusions that can be drawn from this study are the following:

- In order to measure with sufficient precision the difference in the brightness values of the pixels between images referring on different dates, images must undergo geometric correction with a spatial accuracy of about one pixel or higher. This ensures testing for the same number of pixels (which fall within the polygon of the study area) for extracting values and statistical data used to carry out the study. It is evident that geometric correction accuracy would substantially affect horizontal displacement of the disputed area polygon from image to image, which would result in the comparison of different each time and the pixel distortion effects.
- Radiometric correction of the imagery is necessary for the efficiency of detection of changes in temporal imagery satellite data sets, due to the compensation for atmospheric and illumination differences between the various capture dates.
- NDVI complex ratio calculation (or any other ratio depending of the land coverage examined) is also necessary before applying any spectral comparison technique, due to the pixel values normalisation that it leads to.
- Histogram analysis lead to accurate results concerning the temporal land cover of the study.
- Hyper-spectral satellite imagery data sets can be used to extract information about the state of vegetation and to draw conclusions, which may be used as evidence in litigation, concerning claims on whether someone has established property rights by cultivating a certain area for a long period of time.

In conclusion, this study provides a methodology on which engineers can rely. In most southern European countries, it is a common practice for the courts of law to appoint surveying and rural engineers as technical advisors in cases, in order to provide evidence based on the photo interpretation of historic aerial imagery for litigation purposes concerning temporal land-use and land-cover changes and claims.

The present study demonstrates the use of the satellite data as a source of reliable evidence to prove and verify environmental or human-made changes on an ambiguous land-cover or the land-use or a case under dispute. The present study puts together a solid method for utilising satellite multi-spectral imagery for the same purpose offering an educational guide for rural and surveying engineers, among others.

Furthermore, this study presents a change detection remote sensing technique, which can be appropriately altered in order to be used for the detection of changes in other types of land cover and land usage. Environmental engineers can use the same NDVI ratio imagery to detect and compare changes of many types of vegetation coverage by selecting the appropriate control region, depending on the occasion of the study.

In addition, and given that different ratios are suitable for highlighting different types of objects over the hyper-spectral imagery, it is possible to detect and compare changes over different land covers and even concentrations of various earth resources by altering the ratio that has been applied over the hyper-spectral imagery. For example, by utilising the iron-oxide ratio (Band 3/Band 2) [6] that has been used for the detection of the concentrations of iron oxides on the earth’s surface, engineers my form temporal profiles about the quality and quantity of oxide concentrations by applying the same histogram technique over the iron-oxide ratio imagery. In that way, the method proposed in this study could be suitable for dealing with a variety of problems concerning change detection.

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