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Statistical evaluation of spectral capability of satellite QuickBird data in detecting buried archaeological remains

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ABSTRACT: This paper is focused on the Jeffries–Matusita (JM) based spectral characterization of archaeological features performed by using satellite QuickBird imagery. A quantitative evaluation of spectral separability of archaeological marks and their surroundings is carried out by using one of the most widely used indices the JM statistically distance. The selected study area, located in the South of Italy, is related to archaeological marks observed over surfaces with different soil characteristics and vegetation covers. The approach we adopted in this investigation can be fruitfully applied before performing automatic classification for the automatic extraction of archaeological features.

1 INTRODUCTION

Space-borne satellite imagery is increasingly used for archaeological investigations (Lasaponara & Masini 2005, 2006, Masini & Lasaponara 2006), mainly due to recent availability of Very High Resolution (VHR) satellite images, such as IKONOS (1999) and QuickBird (2001). VHR satellite data has heightened the significant improvements that can be achieved in the field of satellite archaeological prospection, compared to the early satellite sensors, such as LandSat or Spot, with spatial resolutions at 30 m or 10 m, respectively. Recent studies performed by Lasaponara & Masini (2005, 2006) showed the high potentiality of satellite QuickBird in detecting the typical archaeological marks linked to the presence of buried archaeological remains.

Nevertheless, the satellite-based identification of spatial features linked to the presence of underlying archaeological remains is one of the most complex and challenging tasks faced by computer vision and photogrammetry communities. This is due to the fact that subsurface archaeological remains tend to produce small anomalies in both spatial and spectral domain. That is why archaeological marks can be easily obscured by noise or other earth material. In this context, the availability of spectral characterization and/or signature of archaeological marks can fruitfully used to improve performance from satellite data processing focused on archaeological investigation. But, up to now, a spectral characterization of archaeological marks is not available. This paper is one of the first efforts addressed to this aim. The investigations were focused on the evaluation of spectral separability observed between archaeological features and their background. In remote sensing data, many features can be computed from multispectral images in order to characterize data classes of interest to the user, in the current case to the archaeologists. In this paper, the spectral characterization was carried out by using the Jeffries– Matusita (JM) distance. Over the years, various techniques based on "statistical separability indices" have been proposed (Swai & Davis 1978). The JM distance was selected because it has been reported by many authors to be an appropriate measure for feature selection (Thomas *et al.* 1987). The JM index is a pairwise distance measure that can be naturally applied to two-classes. Such a measure can be particularly useful prior to an automatic classification process, since it enables the determination of the representativeness of the selected/available training areas.

2 STUDY AREA AND QUICKBIRD DATA DESCRIPTION

2.1 *Quickbird data description*

QuickBird is the commercial satellite that provides the highest spatial resolution images. It has panchromatic and multispectral sensors with resolutions of 61–72 cm and 2.44–2.88 m, respectively, depending upon the off-nadir viewing angle (0–25°). It provides a good stereo geometry and a high revisit frequency of 1–3.5 days depending on latitude. The reader is referred to technical notes available on line at the web site http://www.digitalglobe.com/product/product_docs.shtml.

Table 1. QuickBird spectral channels and typical application.

QuickBird Band	Band Width	Application
Band 1	0.45–0.52 µm (blue)	The blue band is useful for water body penetration, making it a valuable data source for coastal water mapping. It could also be useful for soil/vegetation discrimination, forest type mapping and cultural feature identification. It is highly sensitive to atmospheric contamination
Band 2	0.52–0.60 µm (green)	The green band is useful for measuring green reflectance of vegetation. It can also be used for cultural feature identification
Band 3	0.63–0.69 µm (red)	The red band is useful for measuring green reflectance of vegetation. It can also be used for cultural feature identification used solely, as in the case of soil marks, or in combination with near infra-red as in the case of crop marks
Band 4	0.76–0.90 µm (near infra-red)	The near infra-red band is useful for measuring green reflectance of vegetation. It can also be used for cultural feature identification, such as crop marks

The panchromatic sensor collects information at the visible and near infrared wavelengths and has a bandwidth of 450–900 nm. The multispectral sensor acquires data in four spectral bands from blue to near infrared (NIR). Table 1 shows the band width of the QuickBird spectral channels. Both panchromatic and multispectral sensors offer 11 bit (2,048 grey levels) resolution. The QuickBird imagery products are available at different processing levels (basic, standard, ortho) serving the needs of different users.

Since the successful launch of DigitalGlobe's QuickBird satellite and the availability of the data, QuickBird Imagery has quickly become a widely used data set for large-scale mapping using high-resolution satellites. It has been successfully used for vegetation mapping, fire prevention, urban areas, and recently for archaeological applications (http://www.digitalglobe.com/product/product_docs.shtml.).

2.2 *Study area*

The study area is the archaeological site of Metaponto. It is located between the Basento and Bradano rivers, near the Ionian sea, in the Southeast of the Basilicata Region. It is one of the most important archaeological areas in the South of Italy.

The several archaeological campaigns (Adamesteanu 1973, Carter 1990) stated human presence since mid 8th century B.C., when Metaponto was founded by Greeks coming from the Acaia region. Between the Greek colonization (700 BC – 200 BC) and the Roman age (200 BC – 400 AD) the territory was characterized by an intensive use of the soil as revealed by the several rural sites and an urban settlement that can be observed by surface surveys and excavations, and also by the presence of an extensive system of

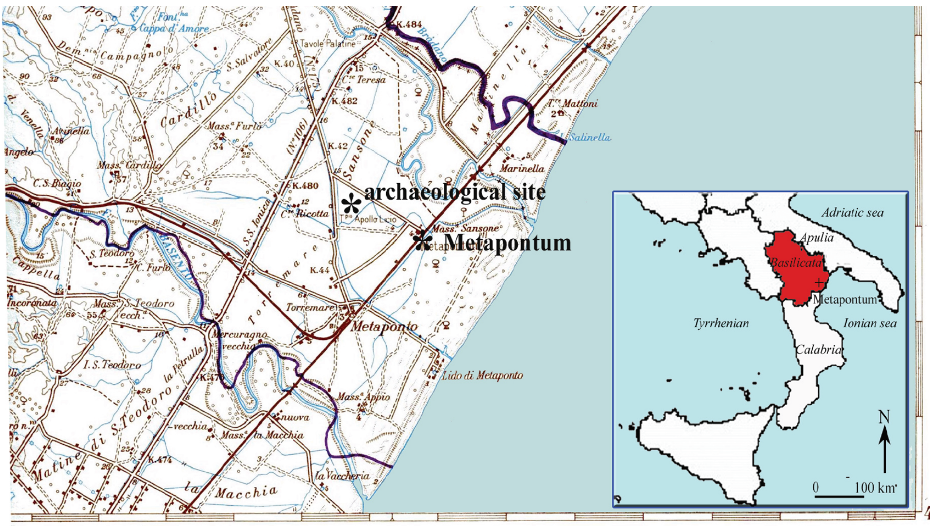

Figure 1. Study area Location.

parallel land divisions (Adamesteanu 1973). In some cases, these lines are thought to have been a network of country lanes or drainage canals (Carter 1990). In other cases, such those located close to the Archaeological Park (Figure 1), they are related to the greek town of Metaponto, whose detection is the object of our analysis.

3 SATELLITE DATA ANALYSIS

3.1 *Jeffries–Matusita (JM) Distance*

The spectral characterization of archaeological features is herein performed by using satellite QuickBird imagery. A quantitative evaluation of spectral separability of archaeological features and their background is carried out by using the Jeffries– Matusita (JM) distance. This is one of the most widely used indices for estimating the spectral separability between two given classes, in the current case: i) archaeological features and ii) background.

The Jeffries–Matusita (JM) distance is obtained from the Bhattacharya distance, shown in equation 1. The Bhattacharya distance can be seen as two components. The first part of equation (1) represents the mean, whereas the second part is the covariance difference. For the BD a greater value indicates a greater average distance.

A drawback of the BD is that such an index does not provide any indication of threshold values for separability.

Jeffries–Matusita (JM) distance is shown in equation 2. The presence of the exponential factor in formula 2 gives an exponentially decreasing weight to increasing separations between spectral classes.

The JM distance has an upper boundary of 1.41 (2), and a lower boundary of 0. The JM distance is asymptotic to the value 2 for increasing class separability. A value of 2 for JM distance would imply that the classification will be performed with 100% accuracy. When the calculated distance is zero, the signatures can be said to be totally inseparable.

Lee & Choi (2000) suggested that:

(i) a *JM distance of 1.09 corresponds to a classification error probability of 10%, and this means that the signatures can be separable;*
(ii) a *JM distance of 1.24 corresponds to a classification error probability of 5%, and this means that the signatures can be highly separable;*

$$BD = \frac{1}{8}(\mu_f \quad \mu_b)^T \left[\frac{\Sigma_f + \Sigma_b}{2}\right]^1 (\mu_f \quad \mu_b) + \frac{1}{2}\ln\frac{\frac{\Sigma_f + \Sigma_b}{2}}{[(|\Sigma_f||\Sigma_b|)^{1/2}]} \qquad (1)$$

where μ_f and μ_b are the mean of and Σ_f and Σ_b are the covariance matrix of archaeological the two considered classes (1) archaeological feature and (2) their background.

$$JM = \sqrt{2(1 - e^{-BD})} \qquad (2)$$

where BD is Bhattacharya distance computed using formula 1.

3.2 *JM-based spectral characterization of archaeological features*

The spectral characterization of archaeological features was carried out by using QuickBird images (Catalog ID 1010010003314001) acquired on 22nd August 2004 with an off nadir view angle of 2 degrees (see Table 2).

The JM distance was applied to the archaeological features of the Metaponto land divisions that were widely investigated by using satellite QuickBird images in some previous studies performed by Masini & Lasaponara (2006).

Table 3 shows the values of JM distance obtained for the archaeological features of Metaponto that in Figure 2 are shown in green colour. The highest values of JM was obtained from NDVI as expected for crop marks. Results from the analyses performed using the JM distance showed that the QuickBird multispectral images and their spectral combinations (such as the NDVI) represent a valuable data source for detecting vegetation marks. According to Lee & Choi (2000) the values of JM distance for NDVI and NIR (c1ose or higher than 1.24) correspond to a classification error probability of 5%, and this means that the signatures can be highly separable.

The values of JM distance for red and green (close or higher than 1.09) correspond to a classification error probability of 5%, and this means that the signatures can be separable.

The values of JM distance for blue and panchromatic are very low and less than 1. This means that the signatures can not be separable. Nevertheless, from a visual inspection, we qualitatively verify that on the basis of all QuickBird images the archaeological features were quite evident. Of course, JM greater value indicates a greater average distance and therefore, a greater performance level for the automatic extraction of the features.

Table 2. QuickBird image metadata of Metaponto.

Acquisition date	2004-08-22
Acquisition time	09:44:10
Cloud cover	0%
Catalog id	1010010003314001
Pan resolution	0.61 meters
Multi resolution	2.45 meters
Environmental quality	90-Excellent
Off-nadir	2 degrees

Table 3. JM values obtained for archaeological features of Metaponto, drawn in green color in Figure 2.

band	JM
pan	0.52
blu	0.61
green	1.02
red	1.20
nir	1.23
ndvi	1.37

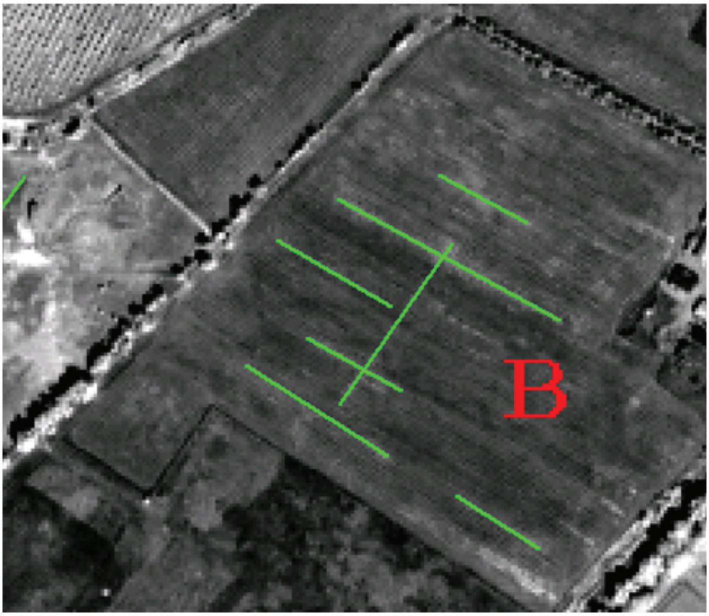

Figure 2. The area B denotes the archaeological features of the study area selected for the current resarch.

4 FINAL REMARKS

Spatial features linked to ancient human transformations of the landscape represent one of the most significant traces of ancient human activities which need to be protected. Unfortunately, due to destructive effects of mechanized agriculture, these archaeological signs are increasingly difficult to identify by using solely panchromatic aerial images. In this paper, we investigated the feasibility of using satellite QuickBird images for the identification of archaeological features. The analysis was focused on the ancient town of Metaponto. Results from the analyses performed using the JM distance showed that the QuickBird multispectral images and their spectral combinations (such as the NDVI) represent a valuable data source for detecting vegetation marks. The JM value of NDVI was the highest observed, whereas, the JM value of QuickBird panchromatic image was the lowest one.

These results pointed out that the importance of performing the assessment of the spectral separability of archaeological features and their background prior to data processing for the extraction of archaeological marks.

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