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Application of new image analysis methods to VHR satellite imagery for archaeological features detection

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ABSTRACT: The potential of high-resolution Ikonos satellite imagery for archaeological investigations was assessed in the well-known site of Ancient Corinth in Central Greece. It represents a major archaeological settlement chosen as test site for comparing different image processing tryouts on satellite imagery aimed at archaeological studies. Results from this research showed that the Ikonos pan-sharpened image products, once properly filtered and analyzed, can represent a valuable data source for identifying the shape of peculiar urban features of an archaeological site.

1 INTRODUCTION

Cultural heritage represents for many communities a common basic historical identity that could be exploited, in the meanwhile, as a cost-effective resource useful for tourism development in different countries. Particularly, the lands facing the Mediterranean Sea experienced during several centuries outstanding civilizations, the deep understanding of which could also be crucial for a proper social, environmental future planning by local authorities.

In this framework, the archaeological investigation provides the basis for detecting the ruins of ancient settlements both carrying classical excavation campaigns and benefiting of the information gathered by geophysical surveys and by interpreting remotely sensed data. Such data have been represented until recently by aerial photos, while since the last two decades satellite or airborne imagery has been more and more used for searching surface anomalies portraying regular (geometric) patterns that may later be attributed to human made structures by the experts.

The recent availability of Very High Resolution (VHR) satellite images, such as IKONOS (1999) and QUICKBIRD (2001), can provide high potentiality for the application of satellite data in the field of archaeology (Carlà *et al*. 2002, De Laet *et al*. 2007, Lasaponara & Masini 2007, Masini & Lapasonara 2007).

Hence, the present study aims at presenting the results of the application of suitable image processing methods to enhance the specific archaeological site and ruins recorded in a IKONOS true color Pan-sharpened image of the ancient Corinth area (Central Greece).

The principal objectives of this research project are:

– to investigate the characteristics of the IKONOS satellite imagery, in order to assess its potential for application in archaeological features detection.
– to use a specific case study to demonstrate how IKONOS satellite imagery could assist with archaeological research.
– to develop and compare appropriate innovative methodologies of image analysis for processing **VHR** data obtaining by-products to assist with their interpretation. The procedure includes gathering and referencing known archaeological structures as mapped in available literature.

2 THE STUDY AREA

Ancient Corinth was one of the biggest and greatest ancient Greek cities. It was on a plateau overlooking the isthmus connecting central Greece, to the north, with Peloponnesus, to the south, and actually 9 km apart from the modern city of Corinth (Figure 1). Due to this position it was of great strategic and economic importance. The peak period of the town started in the 8th century B.C. and lasted until its destruction by the Romans in 146 B.C.

Limited excavations were conducted in 1892 and 1906, while systematic investigations started in 1896 and are still ongoing nowadays. The excavations have brought to light

Figure 1. Location of the Ancient Corinth site.

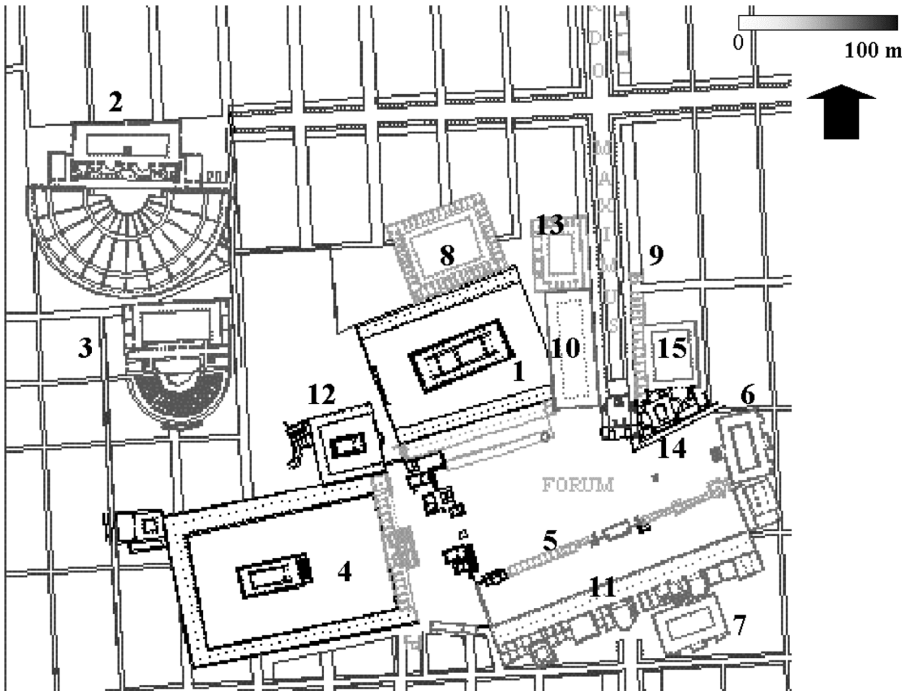

Figure 2. City plan of the ancient Corinth site, (1): Apollo's Temple, (2): Theater, (3): Odeum, (4): temple, (5): Central shops, (6): Julian Basilica, (7): South Basilica, (8): North market, (9): Lechaieon road, (10): Lechaion Basilica, (11): South Stoa, (12): Temple, (13): North marketwest of Lechaion road, (14): Peirine fountain, (15): Peribolos of Apollo (Guilman & Schoenbrun 1993).

Figure 3. View of the ancient city center looking from the Acrocorinth. On the left the standing columns of the Temple of Apollo are visible. On the right side the Lechaion Road can be seen. In between the two (and slightly down) is the ancient agora.

the agora, temples, fountains, shops, a theater and a music school (Figures 2 and 3). The monuments are mainly Roman and only a few are Greek. Excavations have revealed the vast extent of the city, destroyed in Byzantine times by a series of strong earthquakes. The ruins are spread out at the foot of the huge rock of Acrocorinth. The entrance of the archaeological site is nowadays at the southwest side. Passing the entrance and following the Lecheos's streets one should arrive at the central place of the market. The Lecheos's street connected the city with the port of Lecheo in Corinth Gulf. East of the gate there are the remains of Pirini tap, which was in use till the end of 19th century. Close to Pirini tap there are six drawing-up pools, which communicate with a bigger one of 400 m^3 capacity. North of Pirini tap there is Apollo's temple enclosure, which is constituted by a yard surrounded by arcades in some of which Ionian pillars are found. The temple is lying on a low hill and it's one of the most significant archaic temples of Greece. Nowadays, only seven of the thirty-eight columns are standing up. West of Lecheo street there are two foundations of a big Roman royal church. At the west of the market there are the foundations of six small Roman temples and near there are the ruins of a circular pavilion monument with columns of Corinthian style. In the northern part is located the theater, the school of music and finally there are the ruins of the Gymnasium. There are also few remains of the city's walls at the north section of the market, which in the ancient times arrived to the harbor of Lecheo.

3 DATA AND METHODOLOGIES

The present study aims at enhancing the specific archaeological site and ruins recorded in a Ikonos true colour Pan-sharpened scene of the area, dated 31/10/2003. In Table 1 the main characteristics of the IKONOS satellite are shown.

Table 1. Main characteristics of IKONOS satellite.

Lauch date	24/09/1999
Altitude	681 km
Orbit	98.1°, sun synchronous
Panchromatic sensor	B&W 0.45–0.90 μm
Multispectral sensor	Blue 0.45–0.52 μm
	Green 0.51–0.60 μm
	Red 0.63–0.70 μm
	Near IR 0.76–0.85 μm
Image Swath	11.3 km at nadir 13.8 km at 26° off-nadir
Dynamic range	11 bits
Panchromatic pixel resolution	1 m
Multispectral pixel resolution	4 m
Revisit time	Approximately 3 days at 1-meter resolution, 40° latitude

To fulfil this task, different image processing methods, based on suitable statistical and filtering procedures, were applied and compared aiming at obtaining Remote Sensing by-products affordable for archaeological interpretation.

At first, the false colour composite of the Pan-sharpened IKONOS bands were transformed into *Hue-Saturation-Intensity* (**HSI**) images (Foley & van Dam 1982).

The *Intensity* image was, then, replaced with an image obtained by applying a so-called "*morphological*" filter that takes into account the 8-neighbours data. A 8-bit coding of the eight resulting values (0 or 1) was set up, and assigned to the centre of the kernel, according to the results of the difference between the central pixel and the neighbouring one: 1 for positive or null values and 0 for negatives (Abbate *et al.* 2006, Adediran *et al.* 2004). This image was then smoothed by calculating a Mean texture measurement extracted from the co-occurrence matrices (Figure 5)

Another approach applied a pseudo *Sobel* filter (Sobel & Feldman1973) to the Intensity image to calculate module and azimuth by convolving two, horizontal and vertical, 3 × 3 kernels with *Intensity* subsets. In particular, the module image (Figures 4 and 5) turned out to be an interesting edge enhancing by-product which provided results complementary to those obtained by means of the "*morphological*" filter.

Next, a reverse transformation HSI → RGB was applied followed by a "*destretching*" procedure (Gillespie *et al.* 1986) helpful to enhance colour saturation and to give more

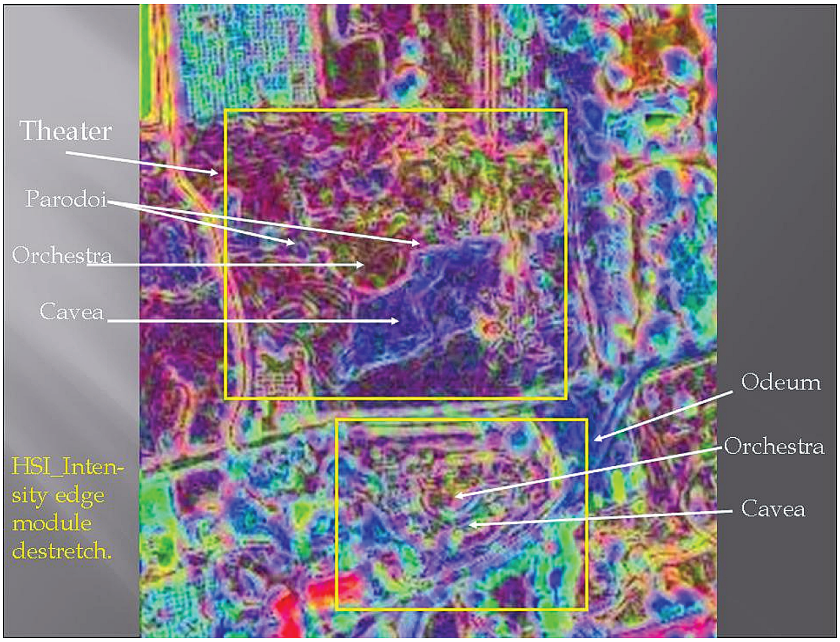

Figure 4. IKONOS destretched HSI Intensity edge module image as interpreted in terms of peculiar Ancient Corinth urban structures.

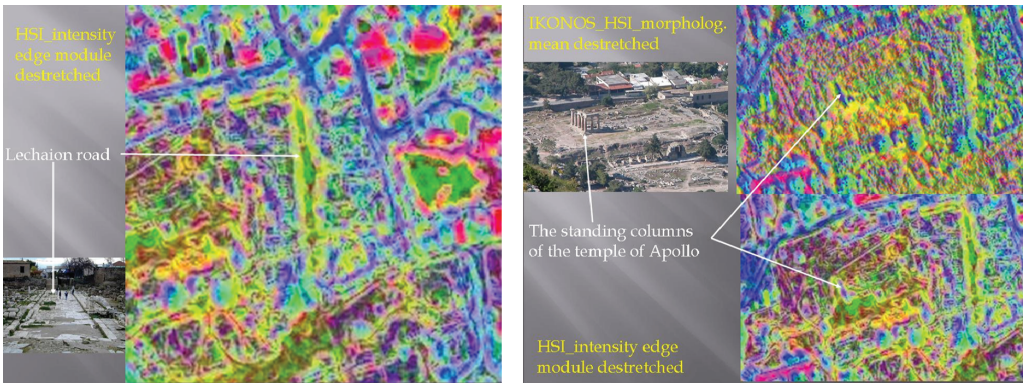

Figure 5. IKONOS destretched HSI Intensity edge module and destretched HSI Intensity morphologically filtered images as interpreted in terms of peculiar Ancient Corinth urban structures.

insight to subtle surface features. A single user interpretation key was delineated to identify peculiar structures of the urban settlement or surface anomalies related to underlying archaeological features.

4 RESULTS AND DISCUSSION

The IKONOS destretched HSI Intensity edge module and the destretched HSI Intensity morphologically filtered images enhance the linear features even if these are circular, typical examples are the Odeum and the theater (see Figure 4).

In the case of the Odeum the *scene* can be clearly detected while the *cavea* (gradine) is only partially visible. The theater is the element of the site, which is almost detectable in both images. In the destretched HSI Intensity morphologically filtered image the *orchestra* and the eastern part of the *cavea* (the western is destroyed) and the two *parodoi* are well displayed.

Poor info is extracted for the temple of Apollo in the two analyzed images (Figure 5) even though in both the Lechaion road is clearly highlighted. The seven columns of the temple, which are still standing, are visible in both image products as linear features and specifically only the five columns with NNW-SSE orientation. This is due to the fact along the other peculiar direction, almost E-W, there exist only three columns which create less shadow than the NNW-SSE stretching columns as the image illumination is from East.

5 CONCLUDING REMARKS

We tried to give insight into the capability of the IKONOS VHR satellite multispectral imagery for identifying archaeological surface features.

To carry out this task, we analyzed a IKONOS scene covering the Ancient Corinth, a major Greek site largely studied by the archaeological community, thus allowing us to have a number of known archaeological structures to be compared.

Different image analysis methods, such as HSI color transformation, edge enhancement and morphological filtering, were applied and, even developed, for processing VHR IKONOS data. The obtained image products were then interpreted and compared in terms of peculiar archaeological features characterization.

Although a relatively high number of images were created, the capability of detecting specific features of the site was not completely achieved. This could be attributed to the small size of the ruins in the site (except for the Theater and the Odeum) as well as to the fact that the site is inserted within the building shell of the new Corinth city.

Future development includes an automatic pattern recognition procedure based on the application of neural network method for classifying IKONOS data after appropriate training of the existing archaeological features.

As for the learning process, a supervised scheme is foreseen for two main reasons. On the one hand, this will allow the efficiency of the procedure to be tightly monitored by not allowing any false alarm to be revealed. On the other hand, this will certainly allow us to gain more insight as to the application of an automatic procedure to solve archaeology related problems based on satellite/airborne imagery. The results of this preliminary work are very important since they will be used as a basis to develop a more general procedure that will ultimately use an unsupervised learning algorithm.

REFERENCES

Abbate, G., Cavalli, R.M., Pascucci, S., Pignatti S. & Poscolieri, M. 2006. Relationships between morphological settings and vegetation covers in a medium relief landscape of Central Italy, *Annals of Geophysics* 49 (1): 153–165.

Adediran, O., Parcharidis, I., Poscolieri, M. & Pavlopoudos, K. 2004. Computer-assisted discrimination of morphological units on north-central Crete (Greece), by applying multivariate statistics to local relief gradients, *Geomorphology* 58: 357–370.

Carla, R., Jacoli, M., Profeti, G. & Venturi, V. 2002. An expert approach to archaeological sites location through remote sensing information. *Proceedings of SPIE* 4886: 630–638.

De Laet, V., Paulissen, E. & Waelkens, M. 2007. Methods for the extraction of archaeological features from very high-resolution Ikonos-2 remote sensing imagery, Hisar (southwest Turkey), *Journal of Archaeological Science* 34 (5): 830–841.

Foley, J. D. & van Dam, A. 1982. *Fundamentals of Interactive Computer Graphics. Boston*, MA, USA: Addison-Wesley.

Gillespie, A. R., Kahle, A. B. & Walker, R. E. 1986. Color enhancement of highly correlated images. I.Decorrelation and HSI contrast stretches, *Remote Sensing of Environment* 20 (3): 209–235.

Gilman, D., Schoenbrun, C. 1993. A Computerized Architectural and Topographical Survey of Ancient Corinth, *Journal of Field Archaeology* (29): 177–190.

Lasaponara, R., Masini, N. 2007. Detection of archaeological crop marks by using satellite QuickBird multispectral imagery, *Journal of Archaeological Science* 34 (2): 214–221.

Masini, N., Lasaponara, R. 2007. Investigating the spectral capability of QuickBird data to detect archaeological remains buried under vegetated and not vegetated areas, *Journal of Cultural Heritage* 8 (1): 53–60.

Sobel, I., Feldman, G. 1973. A 3×3 Isotropic Gradient Operator for Image Processing, presented at a talk at the Stanford Artificial Project in 1968, unpublished but often cited, in Pattern Classification and Scene Analysis, Duda, R., Hart, P., John Wiley and Sons: 271–272.