Remote sensing Archaeology knowledge transfer: examples from the ATHENA Twinning project

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ABSTRACT

ATHENA is an on-going Horizon 2020 Twinning project aiming to promote remote sensing technologies for cultural heritage (CH) applications in Cyprus. ATHENA project brings together the Eratosthenes Research Center (ERC) of the Cyprus University of Technology (CUT) with two internationally leading institutions of Europe, namely the National Research Council of Italy (CNR) and the German Aerospace Centre (DLR). The project's scope is to position the ERC regionally and stimulate future cooperation through placements at partner institutions and enhance the research and academic profile of all participants. The scientific strengthening and networking achieved through the ATHENA project could be of great benefit not only for Cyprus but for the entire Eastern Mediterranean, bearing a plethora of archaeological sites and monuments urgently calling for monitoring and safeguarding.

The preservation of CH and landscape comprises a strategic priority not only to guarantee cultural treasures and evidence of the human past to future generations, but also to exploit them as a strategic and valuable economic asset. The objective of this paper is to present knowledge transfer examples achieved from the ATHENA project through intense training activities. These activities were also designed to enhance the scientific profile of the research staff and to accelerate the development of research capabilities of the ERC. At the same time the results from the training activities were also exploited to promote earth observation knowledge and best practices intended for CH. The activities included active and passive remote sensing data used for archaeological applications, Synthetic Aperture Radar (SAR) image analysis for change and deformation detection, monitoring of risk factors related to cultural heritage sites including archaeological looting etc.

Keywords: ATHENA, Archaeology, training activities, Twinning project, Space technologies

INTRODUCTION

In the last decade earth observation and remote sensing has been widely used to support archaeological research and cultural heritage management. This is well documented in the numerous publications of the last years and from bibliometric statistics [1, 2]. In addition to this, joint research projects are funded so as to promote sustainability and best practices against natural and anthropogenic hazards [3,4]. The potential use of earth observation and remote sensing has been also recognized by UNESCO who has supported the creation of the first International Centre on Space Technologies for Natural and Cultural Heritage (HIST) [5]. It was officially inaugurated in 2011 under the auspices of UNESCO and with support from its host, the Center for Earth Observation and Digital Earth (CEODE), Chinese Academy of Sciences (CAS) was aiming to "*build the capacity of UNESCO Member States to use space-based Earth*

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observation to monitor, document, model, and present natural and cultural heritage sites of national or international significance" [5].

While Europe is, along with USA and China, one of the leading members of the world, regarding the systematic exploitation of space earth observation and remote sensing technology, research activities are still fragmented within the continent. To this end, Horizon 2020 (H2020) -the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available from 2014 to 2020- has dedicated for specific Coordination and Support Action (CSA) calls so as to enhance networking activities between the research institutions of low performance in research countries and internationally-leading counterparts at EU level.

The 3-year duration H2020 ATHENA proposal submitted under this call (i.e. Widespread Twinning 2015) was eventually approved by the European Commission with a total budget of approximately €1 million, and it is currently running for the period Dec. 2015 until Nov. 2018. The ATHENA project [6] is aiming to enhance the capacity of the Archaeology and Cultural Heritage Section [7], of the Remote Sensing and Geo-Environment Laboratory, part of the Eratosthenes Research Center [8], by bringing together researchers of the group with leading experts in the field from the National Research Council of Italy (CNR) [9] and the German Aerospace Centre (DLR) [10].

The National Research Council of Italy (CNR) has a strong record in the exploitation of remote sensing technologies for cultural heritage in various parts of the world, with also scientific missions in Southern America and China, while the German Aerospace Centre (DLR) is a leading institute in the domain of space technologies. Following an internal SWOT analysis of the group and based on the research agenda of the leading institutions, a detailed knowledge transfer program has been set up for the whole duration of the ATHENA project. This is outlined in the following sections along with some of the results.

KNOWLEDGE TRANSFER

Research Topics

The ATHENA project focuses on the knowledge related to cultural heritage implementing actions based on multidisciplinary collaborations and closes the gap between cross-disciplinary research and methods through different scientific domains. It is expected that the ATHENA project directly and indirectly benefits the project consortium as well as associated stakeholders. The combination of innovative methodologies to enhance the understanding of European cultural heritage by means of remote sensing techniques brought new knowledge, collaboration across disciplines, and social benefits. The innovative procedures and applications enabled remote communication and collaboration across the industry, professionals, experts, researchers and academia.

The main research topics of the ATHENA project that were set up for training and further studding included the following:

- Use of remote sensing (RS) techniques for the detection of buried antiquities and archaeological residues.
- Use of RS techniques and environmental information systems for supporting, understanding, analyzing, documenting and monitoring the archaeological landscape, systematic and rescue archaeological excavations, as well as isolate monuments and their related environment.
- Documentation and structural analysis of standing remains of CH; monitoring of known sites regarding their vulnerability and exposure to natural and anthropogenic hazards.
- RS for estimation of risk factors related to CH sites, such as natural (landslides, flooding, sea level rise) and man-made (i.e. impact of urban and modern infrastructures, land use, looting, deliberate destruction thru war and conflict).
- Experimental RS applications for archaeological investigations.

The above research activities were envisaged through various close-range remote sensing techniques such as ground penetrating radar, and middle range (UAV's), distant from low Earth orbit (satellite imagery in SAR, optical and hyperspectral domain), desk-base (GIS, FEM, etc.) and their integration with archaeological and cultural context.

Research approach

The methodological approach of the ATHENA project is based upon the support activities carried out from the internationally leading research institutions. These integrated activities thereby contribute to the overall programme and scientific objectives of the project. The approach of the project is described below:

- Detailed literature reviews provide the necessary background knowledge and assist current staff of the low performing country in formulating well-defined background and target its tasks.
- Evaluation of existing gaps of the CUT's lab both in terms of knowledge, capacity, equipment etc.
- Training of the CUT researchers from all leading research institutions in two main thematic areas: Remote sensing in Archaeology (by CNR) and new remote sensing technologies and tools and Environmental Information Systems (by DLR), including various subthemes, such as: interferometry/radar, hyperspectral processing, multi-temporal RS analysis, satellite monitoring for archaeological looting, Copernicus contribution to CH.
- Short term visits of researchers from Cyprus to the project partner organizations DLR and CNR and vice versa.
- Synthesis and integration of different remote sensing techniques for supporting archaeological research and cultural heritage management and monitoring.
- Joint workshops and summer schools with all project partners, joint interpretation, presentation and archiving of the data from the various activities carried out during the collaboration.

KNOWLEDGE TRANFER EXAMPLES

Research activities

Among the first examples of the research between the CUT and CNR teams was the application and evaluation of optical satellite images for the detection of buried relics nearby the modern village of Lucera, in the Tavoliere territory (Apulia region) in Southern Italy. In this area, a large number of crop marks that reveal traces of long human habitation since the Neolithic age have been identified, while the "extraordinary interest in studying crop marks in this area is explained by the presence of a great morphological variety of traces ranging from curvilinear to linear and quadrangular shapes, linked to the different historical phases of human presence at the site" [11].

The experiments were contacted using both GeoEye and Quickbird images, by applying various image enhancement techniques such as the Normalized Difference Vegetation Index (NDVI), Simple Ratio Index (SR) as well as to evaluate the performance of the orthogonal equations [12, 13]. The results have shown "the potential use of the linear equations and in particular, the use of ratios between the different components can improve the detection of crop marks even more. The best discriminability of the Neolithic crop marks is obtained by the vegetation/crop and vegetation/soil ratios. In addition these ratios were able to improve the quality of the images in shadow areas [11]. Some results from this application are shown in Figure 1.

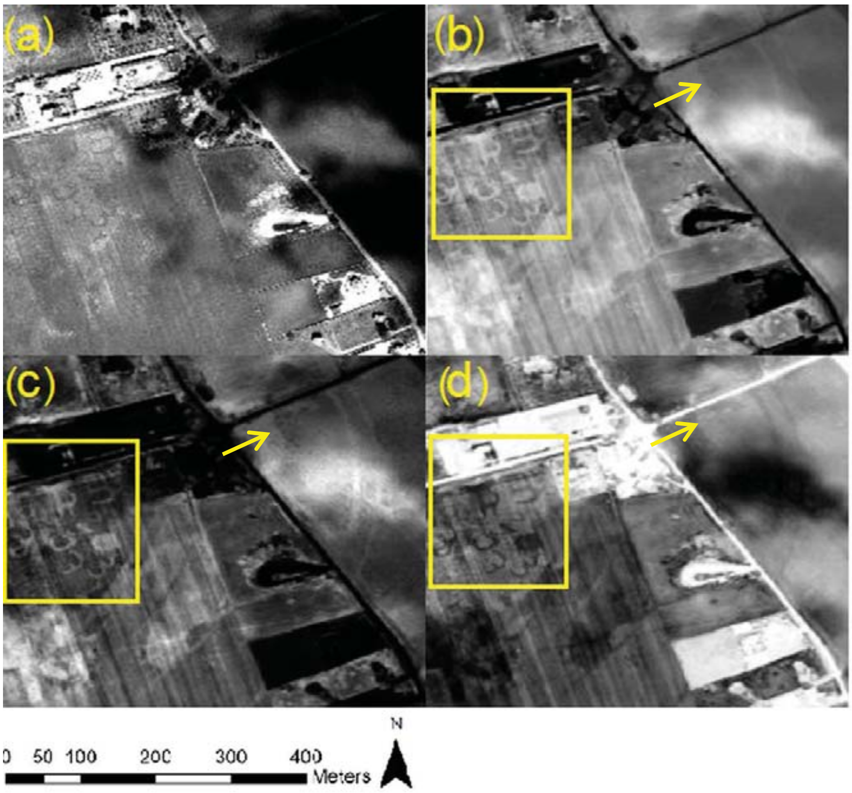
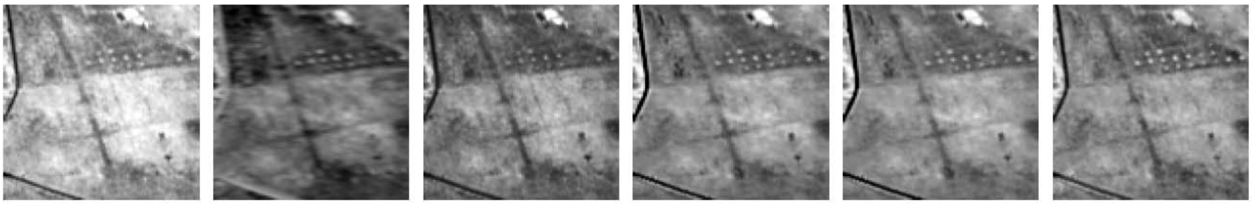
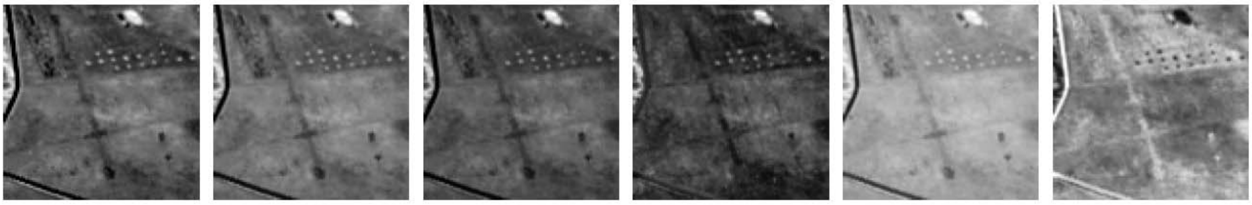


Figure 1. Palmori archaeological site (41.545551°N and 15.436549°E, WGS 84). (a) Panchromatic band; (b) vegetation coefficient; (c) NIR/red ratio; and (d) vegetation/crop ratio applied in the 2012 GeoEye image. The vegetation coefficient and the NIR/red and vegetation/crop mark ratios are able to reduce the shadow caused by the clouds. The yellow arrows indicate part of a curvilinear mark, referable to a ditch bordering Palmori settlement. The visual comparison of Figure 5a,b shows that the features evident from the 2012 scene are not visible in the 2007 picture and vice versa. Figure from [11].

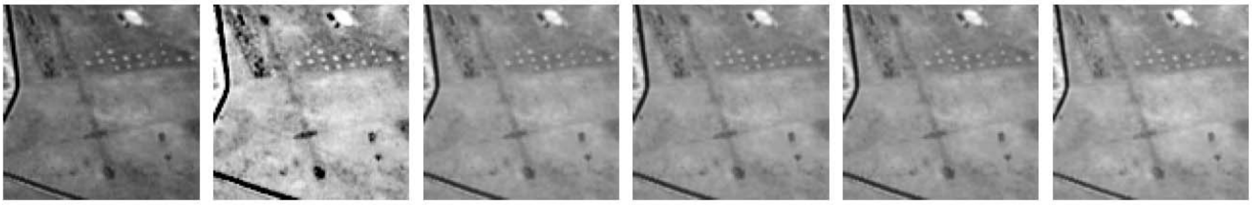
In parallel with the above research, the research group was working with the DLR researchers in order to asses several hyperspectral indicators for the detection of buried archaeological relics. While the application of several vegetation indices and other image features has been widely used in the past in order to enhance the interpretation of satellite images, it has not been tested for their performance. To this end, the research was oriented to "the evaluation of the statistical dependence between the extracted features and a digital map indicating the presence of buried structures using information theoretical notions. Based on the obtained scores on known targets, the features can be ranked and the most suitable can be chosen to aid in the discovery of previously undetected crop marks in the area under similar conditions" [14]. Three case studies were reported in this analysis: the Roman buried remains of Carnuntum (Austria), the underground structures of Selinunte in the South of Italy, and the buried street relics of Pherai (Velestino) in central Greece. This semi-automatic ranking of the indices—for each specific case study—according to their 'archaeological' informational content may help experts in focusing on other areas in close proximities, based on the most meaningful indices for further investigation activities. Such researches are usually carried out via visual analysis, and the pre-selection of the most suitable spectral features could maximize the success rate of the interpretation of crop marks. An example of the ranking of several vegetation indices based on their "archaeological information" for the case study of Selinunte in Italy is given below:



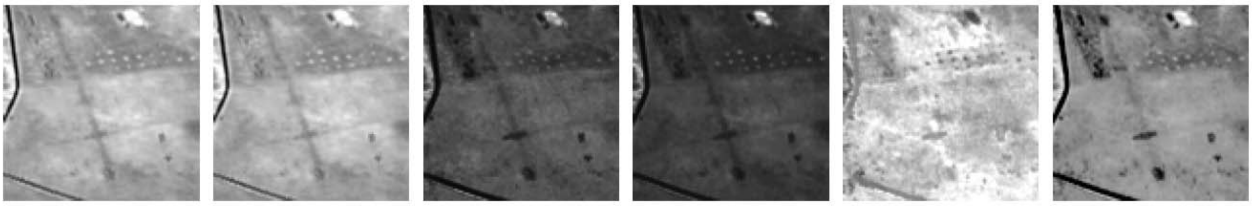
1 - TCARI, 100% 2 - NDMI, 98.3% 3 - MCARI, 93.5% 4 - TVI, 90.9% 5 - MTVI, 90.9% 6 - MCARI2, 89.6%



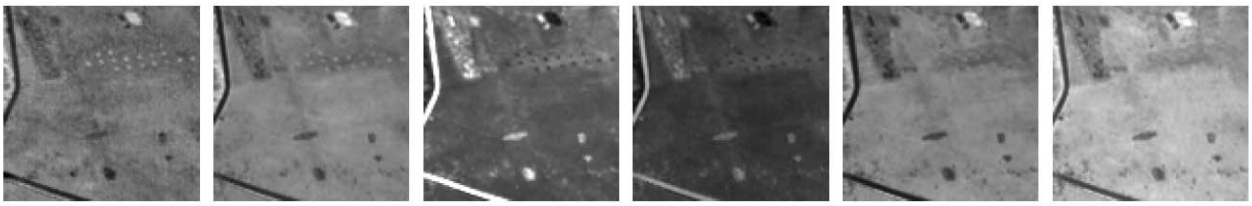
7 - MRENDVI, 88.2% 8 - ARVI, 85.6% 9 - EVI, 84.3% 10 - VARI, 83.9% 11 - TrVI, 83.3% 12 - PSRI, 82.7%



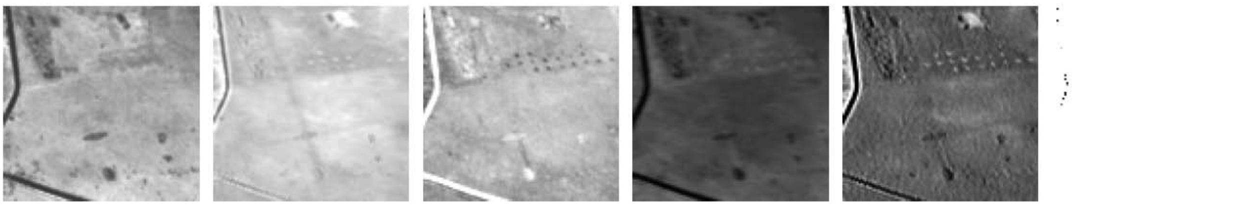
13 - RENDVI, 82.5% 14 - GARI, 81.7% 15 - IPVI, 81.7% 16 - NDVI, 81.6% 17 - SAVI, 81.3% 18 - RDVI, 77.0%



19 - GEMI, 77.0% 20 - DVI, 75.9% 21 - CRI1, 74.7% 22 - SR, 69.2% 23 - IronOxide, 67.5% 24 - GNDVI, 66.1%



25 - PRI, 64.5% 26 - GRVI, 59.0% 27 - SGI, 56.3% 28 - NDSI, 54.5% 29 - CRI2, 52.8% 30 - ARI2, 50.9%



31 - ARI1, 48.9% 32 - GDVI, 44.5% 33 - NLI, 42.0% 34 - BAI, 36.7% 35 - VRE1, 35.0% 36 - SIPI, 0.0%

Figure 2. Detail of spectral indices computed for the Selinunte dataset. The indices are sorted from best to worst, according to the mutual information with the main crossroad in the area. A score is derived as the relative mutual information with respect to the one computed for the best index. The buried structures become less evident as the mutual information decreases. Figure from [14].

The main result of this research was showing that spectral indices, whose efficiency at discriminating crop marks depends on the case of study and the geographical area, can be ranked on a known study site and successfully transferred to a nearby site under investigation, under the assumption that variation in vegetation and soil characteristics are limited in a restricted area. This helps researchers in selecting the most suitable spectral indices at hand among hundreds of possibilities to carry out a meaningful analysis.

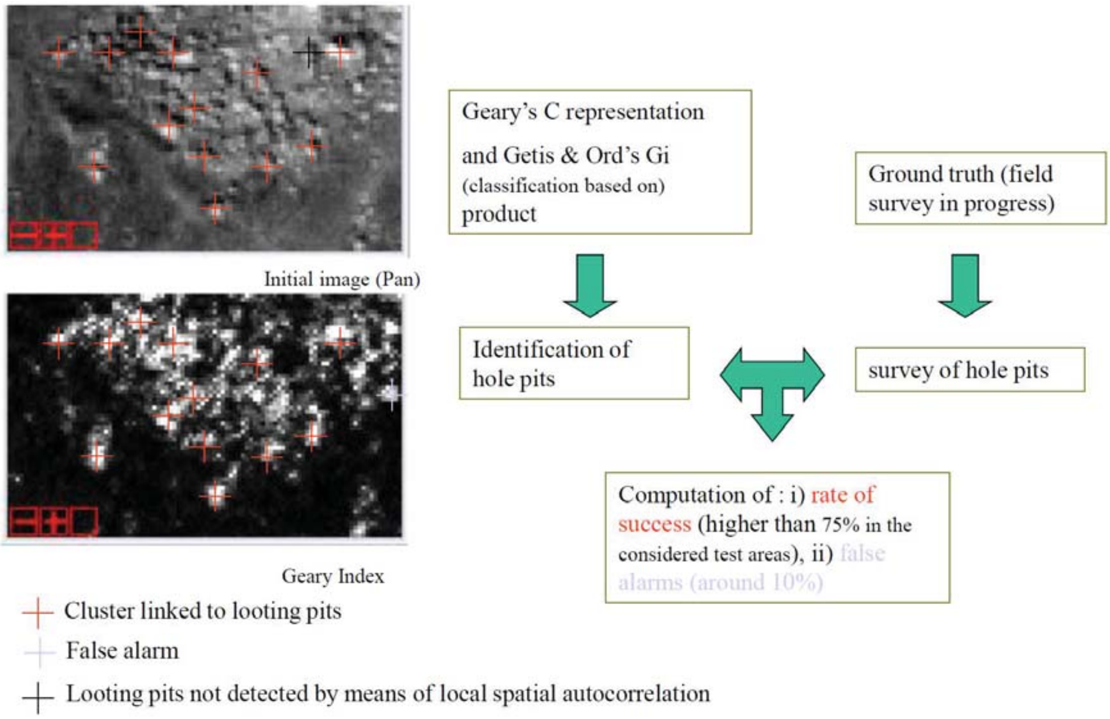
Training activities

An example of training activities and hands-on experience was the "Archaeological looting: Ancient problems and New approaches based on Remote Sensing" training event carried out in CUT premises. The preservation of cultural heritage and landscape is today a strategic priority, not only to preseve cultural treasures and evidence of the human past for future generations, but also to exploit them as a strategic and valuable economic asset, if inspired by sustainable development strategies. This is an extremely important key factor for countries which are owners of an extraordinary cultural legacy, which is particularly fragile due to its specific characteristics and risks at which CH is continuously exposed. Taking advantage of large-spatial coverage and a detailed spectral information, satellite remote sensing can be usefully adopted for contrasting looting, especially in countries located in South America or the Middle East, where the surveillance on site is not particularly effective and time consuming, or non practicable due to military or political restrictions [15].

The training activities organized by CNR were focused on the characterization of the looting phenomenon from a multi-faced prospective (as detailed below). In particular, the training activities were focused on the use of high spatial resolution satellite and aerial optical images and Lidar acquisition to quantitatively assess looting. An overview of methodologies and data processing for the identification and quantification of looting features (using both single date and multitemporal satellite images) were discussed for several study areas.

Moreover, advanced data processing based on both autocorrelation statistics and unsupervised classification have been presented, applied and discussed for significant study areas, as Dura Europos [16]; selected in Syria. The main topic were deeply focalized:

1. Looting as a complex problem
   - black market of looted items
   - social and anthropological view of looters;
2. Looting features from above: physical and spectral characteristics
   - Looting from optical satellite data
   - Looting from SAR satellite data
   - Looting from LIDAR
   - Looting from UAV optical image
3. An overview of Looting
   - Looting in diverse countries from Middle East to Peru, from Asia to Europe
   - Looting mapping and quantification
   - Visual inspection, Crowd sourcing and automatic data processing to map and quantify looting
4. Data processing from looting feature extraction
   - Classification to automatically detect looting in desert environment



In Cahuachi, the detection of looting pits on mounds has been significantly improved by applying local spatial autocorrelation statistics.

Such improvement is still more evident if we compare the panchromatic satellite time series with the correspondent time series processed by local spatial autocorrelation statistics

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