

Advancement in Automatic Monitoring and Detection of Archaeological Sites Using a Hybrid Process of Remote Sensing, GIS Techniques and a Shape Detection Algorithm

Alessio DI IORIO^{1,2}, Nazzareno STRACCIA², and Renzo CARLUCCI³

Rovsing A/S, Skovlunde, Denmark, E-mail: adi@rovsing.dk , almasistemi@fastwebnet.it

ALMA Sistemi SAS, Rome, Italy, E-mail: nazzareno.straccia@tiscali.it

A&C2000 s.r.l. Rome, Italy, E-mail: rcarlucci@aec2000.eu

Abstract. The method developed in the frame of the project HORUS (Heritage Observation and Retrieval Under Sand funded by European Space Agency) for the automatic monitoring and identification of lost or undiscovered archaeological sites in Egypt has been improved and applied to the new available high resolution radar images by Cosmo Sky-Med satellites. The use of active high resolution active sensors enables continue monitoring of the target area with all whether condition (day, night with any cloudy coverage) and Cosmo Sky-Med satellites are mainly devoted to observe the “Mediterranean area (“Med in fact is for “Mediterranean”) where is the highest density of the Archaeological sites in the world. The method uses shape detection techniques on satellite imagery superposed in a GIS environment. For an area of interest, the EO data available from various satellites is pre-processed and from historical plans a shape file of the archaeological structure of interest is produced. A shape detection algorithm employing a shape matched operator is applied to the EO image to produce a detection image identifying the most probable location of the archaeological structure of interest. The shape-matched operator employed is the derivative of double exponential (DODE) operator. The final product is a GIS data set assembled as a list of required features and layers, all converted and processed in the same Geographical Reference System. The article shows the most recent advancement using an enhanced version of the operator applied to high resolution X-band SAR images by Cosmo Sky-Med.

Keywords. Archeological site monitoring and detection, GIS, remote sensing, SAR, Cosmo Sky-Med

Introduction

The work subsequently described has been performed as advancement of the ESA Data User Element (DUE) Innovator User Partnership project: Heritage Observation and Retrieval under Sand, (HORUS). The main objective of the Innovator User partnership is to demonstrate an innovative Earth Observation (EO) based information service to End-users.

A detailed description of project HORUS can be found in [3], however some concepts are here-under reported for completeness. The advancement is related to the application of the techniques developed under HORUS to the new available radar data.

End-user requirements

The End-user of the HORUS DUE Innovator project is the Center for Documentation of Cultural and Natural Heritage (CULTNAT), Egypt. The conservation and management of Egypt's archaeological heritage is an important task made more difficult by the overwhelming number of sites which are distributed all over the country and by the ever-increasing pace of urbanization around archaeological sites. Current practices and resources do not allow the analysis and control of all archaeological areas in Egypt. By combining the historical and cultural knowledge and experience of the End-user with automatic procedures and algorithms for searching EO data the expectation is to

reduce costs and time needed to discover new sites and protect existing ones. Specifically, a service required by the End-user and supplied by the HORUS project is for the identification of lost or undiscovered archaeological sites. Sites are lost in the sense that they have previously been excavated but inadequately recorded and are now covered in sand again. Another identified service is related to the continue monitoring of the archaeological sites in Egypt to identify illegal excavations. Preliminary results assessed by the End-user in the frame of the project HORUS indicate that the approach is viable and beneficial. Advance results carried out by using new high resolution radar data demonstrates the feasibility of the user service for Egypt while indicating the methodology is viable for a much more wide service in order to cover all the Mediterranean area where the great majority of world heritage can be found.

End-user scenarios

Various scenarios are envisaged by the End-user where the approximate locations of archaeological sites are known to a greater or lesser extent and where plans of archaeological structures exist with varying degrees of accuracy. From local knowledge and domain expertise, the End-user may also be aware that undefined structures may be present underground in a particular region. A representative geographical area of interest to the End-user is the Saqqara site, situated approximately 25 km south west of Cairo, which is suitable as a reference site given the large amount of existing data. Similarly, the Fayoum - Medinet Madi region is also used.

1. Process description

The process to provide the End-user service of locating archaeological structures consists of:

- EO image acquisition and pre-processing
- Archive search for historical maps and drawings of archaeological structures of interest
- Construction of shape matched operator and shape detection
- Integration into GIS framework

1.1. EO image acquisition and pre-processing

The approach for selecting EO data has been to include all data that could contribute to the location of ancient structures below sand. It has previously been demonstrated that L band and C band radar has ground penetrating ability in dry sand in particular. Consequently, the use of L band synthetic aperture radar (SAR) images generated by JERS1 and the C band SAR images of ERS1, ERS2 and Envisat have been investigated in the frame of project HORUS. Further investigation on SAR images is on-going (see section V). Optical data is also considered as sub surface structures can cause changes in topography, sand accumulation, humidity and other features. Very high resolution (VHR) optical data in the form of QuickBird and Ikonos images have also been used to readily validate the results obtained. Before performing shape detection, the EO images are calibrated, ortho-rectified and geo-referenced in the GIS system of the End-user.

1.2. Historical archive search

The End-user is responsible for identifying and procuring historical data relating to the areas of interest.

The Serapeum complex at Saqqara is of particular interest, having been rediscovered by the French archaeologist A. E. Mariette in 1850. Historical drawings of the complex are shown in Fig. 1 and, where available, the historical archives have been supplemented with drawings of more recent excavations as in Fig. 2.

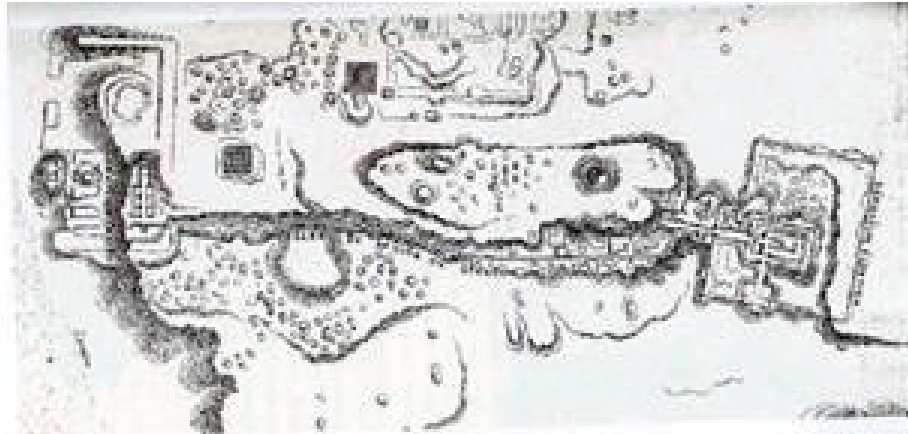


Figure 1. Mariette Plan 1882

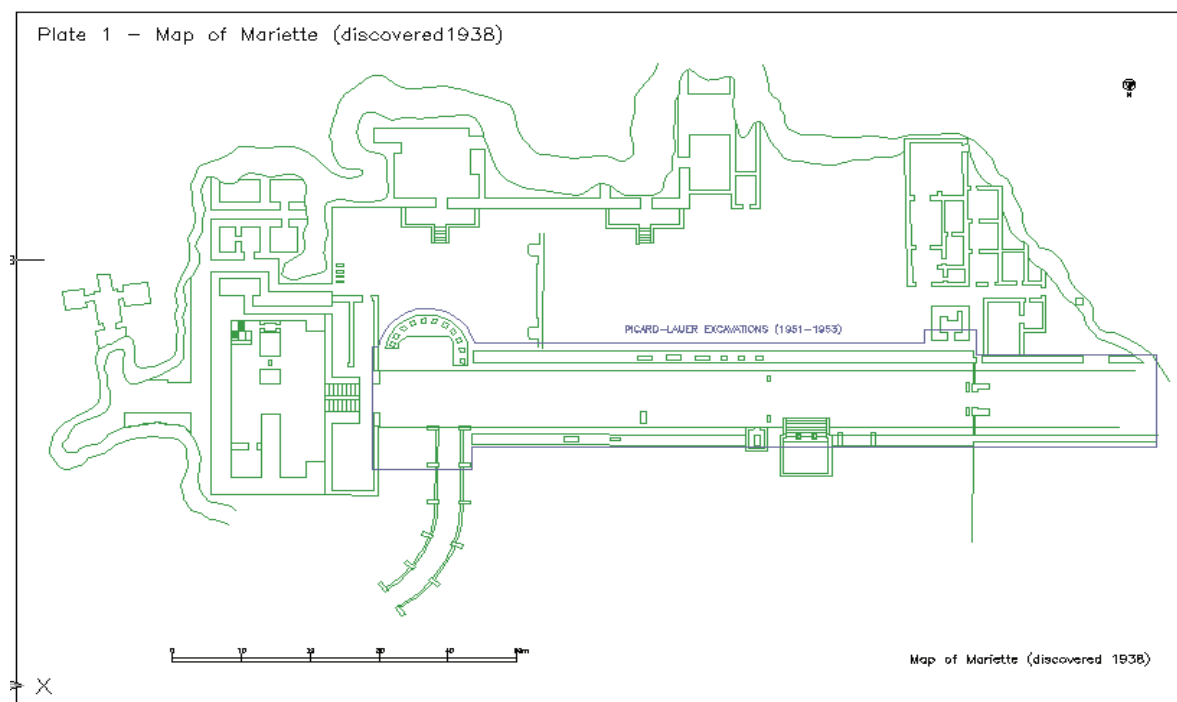


Figure 1. Picard Lauer excavations 1951-1953

1.3. Shaped matched operator and shape detection

The selected operator is the step expansion filter (SEF) derived as an optimal step edge filter. The SEF is the derivative of the double exponential (DODE) filter derived by [1]. The shape matched operator is defined by extending the optimal edge operator along the shape boundary. A full discussion and justification of the optimal step edge operator used in this application can be found in [3].

1.4. Integration into GIS framework

The intermediate results of the shape detection process are shape detection layers which are image files, in this case in Tagged Information File Format (TIFF), indicating the most probable positions of the shape being searched for. An analysis data file defining the pixel values of the locations is also created. To be of maximum use to the End-user, the shape detection layers are then integrated into a GIS environment where they can be combined with additional features and information. The

integrated GIS data set can then be used to optimize the field resources of the End-user. Detail of Saqqara site superimposed with GIS layers

2. Shape detection process

The shape detection process consists of two distinct stages, an operator preparation stage and a shape detection stage.

2.1. Operator preparation stage

The purpose of the operator preparation stage is to convert the shape file derived from information supplied by the End-user into the shape matched operator for use in the shape detection stage.

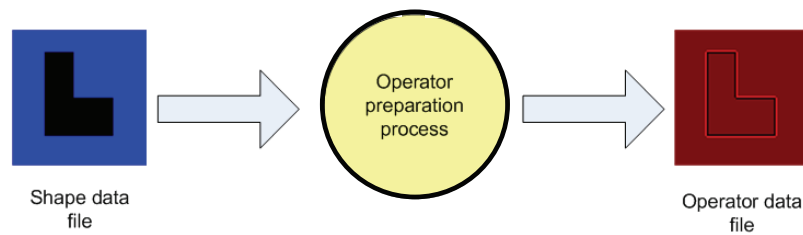


Figure 2. Operator preparation stage

The shape file is a TIFF file consisting of the shape of the architectural structure to be searched for, typically derived from an historical drawing. Edge refinement and enhancement is performed as required and the image is converted to black and white to simplify subsequent processing. An algorithm then detects the shape boundary and a rising edge boundary is represented by the pixel pair (1, -1) and a falling edge boundary by the pixel pair (-1, 1). All other pixel values are set to zero. A smoothing operator is applied to the rows and columns of the resulting shape boundary matrix. Consequently, the step edges are expanded according to the optimal edge operator and the resulting matrix represents the optimal shape matched operator.

2.2. Shape detection stage

In the shape detection process, the various layers of the EO TIFF files, for example the RGB layers of optical images, are individually convolved with the kernel defined by optimal shape matched operator.

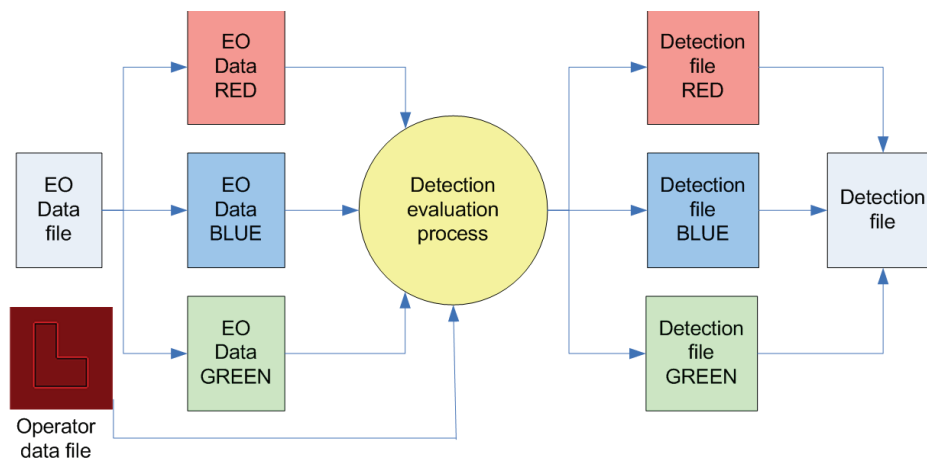


Figure 3. Shape detection stage

The results of the individual convolutions are combined and the maximum values identified, corresponding to the most probable locations of the archaeological structure of interest. The positions of the maxim, within a certain range of the maximum defined by the sensitivity level parameter in an associated XML file, are stored in a data file and are highlighted in a corresponding detection TIFF file which is integrated as a layer in the GIS system of the End-user.

3. HORUS results

The application was initially tested for shape recognition performance with an archaeological structure in the Medinet Madi region that was clearly visible in an Ikonos optical image which could therefore be readily validated.

The corresponding shape file of Fig. 5 was produced where the size and orientation of the shape was known. The EO file was an Ikonos image of the Fayoum - Medinet Madi region. The EO image can be seen in Fig. 6 as part of an ArcGIS dataset with the archaeological drawing superimposed on the EO image.



Figure 5. Shape to be detected

Applying the detection algorithm on the image generates a detection layer where the region producing the maximum response to the shape matched operator is highlighted in yellow. Responses with values lying within a specified range of the maximum are highlighted in red. The shape detection layer is integrated into the GIS dataset and superimposed on the corresponding layers. Fig. 6 shows an enlarged area of the detection layer in the GIS dataset with the structure searched for having been correctly located and highlighted with a yellow square.

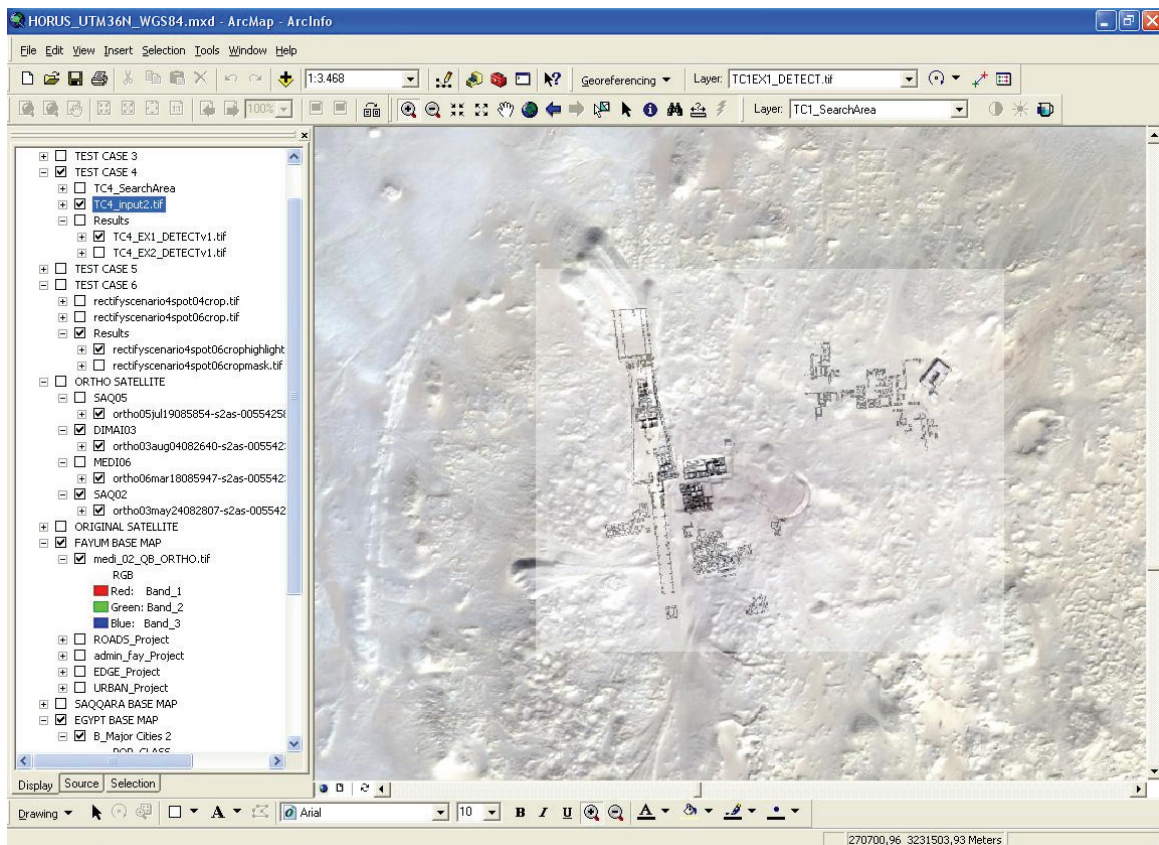


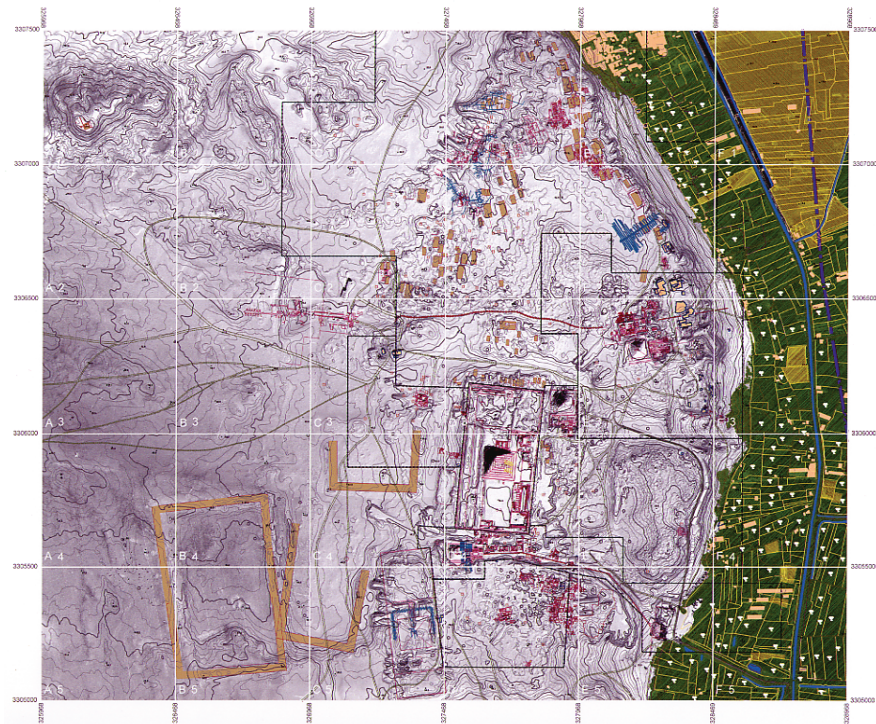
Figure 6. ArcGIS dataset showing an Ikonos image and archaeological plan of the Medinet Madi region.

A more representative test is shown in Fig. 7 to Fig. 10 which covers the Medinet Madi site. A drawing of the archaeological structures in the region of interest is shown in Fig. 5 with the test archaeological structure to be searched for, circled. From the detailed drawing a simple shape file, is produced to provide the input to the application along with the EO image.



Figure 7. Shape detection result layer

Of particular interest to the End-user in the Saqqara area is the Serapeum complex, a gallery of tombs cut from rock and serving as the burial place of the sacred Apis bull. The Serapeum complex is approximately located in the centre of Fig. 8. This was rediscovered in more recent times by the French archaeologist A. E. Mariette during excavations in 1851. Further excavations by Mariette revealed the Dromos, the ceremonial approach to the Serapeum as illustrated in Fig. 2. With a few exceptions like the semicircular arrangement of statues known as the Philosophers' Circle, the area is now buried under sand again.



For validation, the semicircular structure was searched for using the shape file in the region of interest of the QuickBird image.



Figure 9. Philosophers' Circle shape file

Applying the shape detection algorithm correctly identifies the structure as seen in the enlarged area of the detection layer in Fig. 10. Using the detected Philosophers' Circle structure, the location of the Serapeum can be seen by superimposing the drawing of Fig. 3 made from previous excavations.

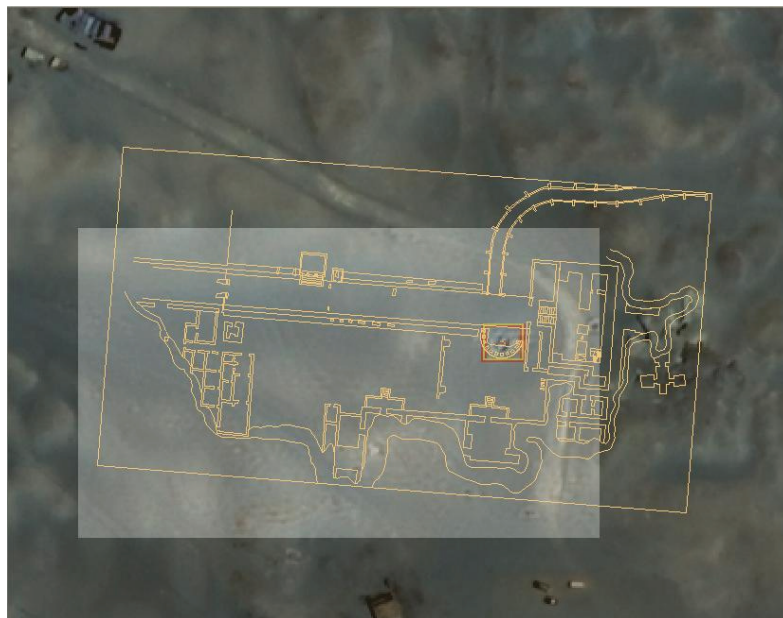


Figure 10. Detection of “Philosopher circle” superimposing Picard Lauer excavation documentation

In order to reveal features under sand, L band radar images of the area generated by JERS1 have been considered. Fig. 11 is a JERS1 L band image of the Saqqara area having a resolution of 12.5 m. The step pyramid of Djoser can be discerned to the right of centre in the image.

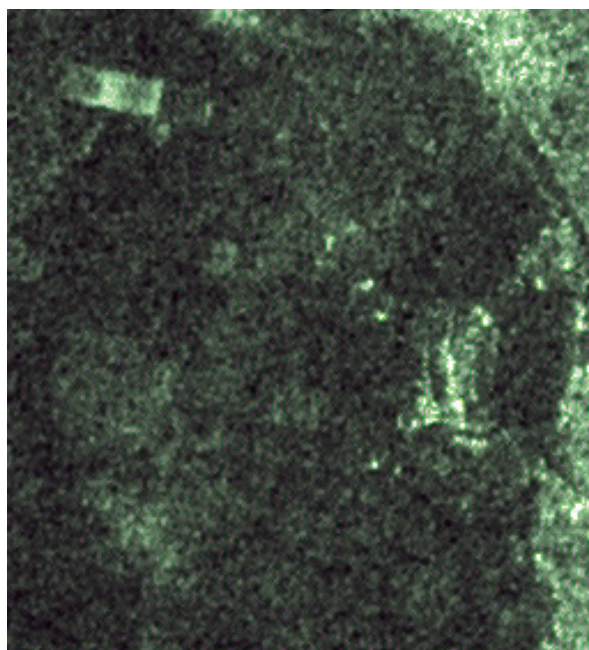


Figure 11. JERS1 image of the central Saqqara region around the Serapeum complex

From existing knowledge of the size and shape of structures at the Serapeum complex as shown in Fig. 3, a simplified shape file can be produced, Fig. 13.



Figure 12. Simplified Serapeum site shape

Applying the shape detection application to the image in Fig. 11 using the shape defined by Fig. 12 produces the shape detection result layer shown in Fig. 13

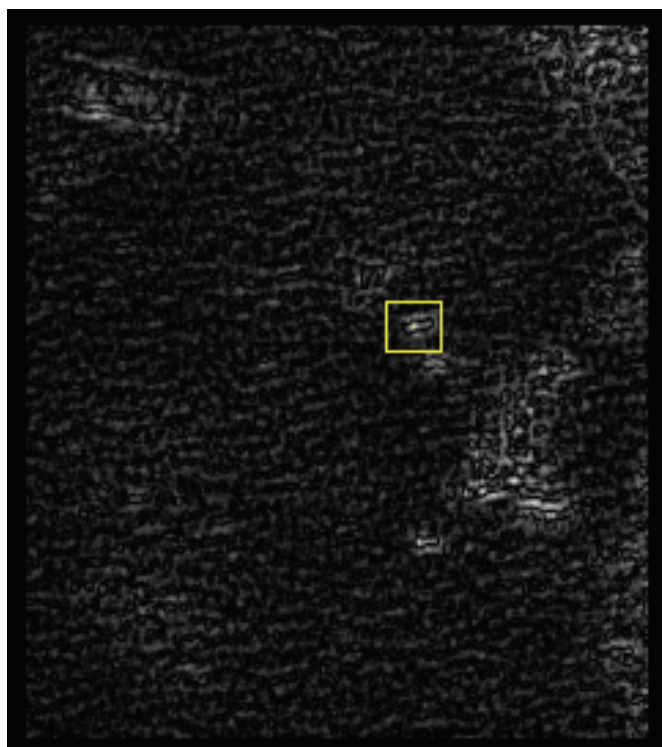


Figure 13. Detection of the Seraphum complex

The application has uniquely identified a region which corresponds to the region of the Serapeum complex.

4. SAR ENHANCEMENTS

After high resolution radar satellite missions like TerraSAR-X and Cosmo SkyMed have been launched in 2007, space borne SAR images can reach spatial resolutions below one meter in azimuth and range. Nevertheless, visual analysis of features showing up in images is still challenging.

Furthermore the short revisit time and coverage of the Cosmo SkyMed constellation enable a near real-time monitoring service for several applications.

Now in order to detect archaeological sites an additional radar layer can be added to the optical ones. This new layer can add, due the coherent source illuminating the scene, at least three different contributions.

- Better penetrability of the radar on the soil, especially on dry terrains (about 3-10 cm in X band depending on soil moisture) and phase unwrapping analysis.
- Humidity map generation of the terrain.
- Simulated reconstruction of the described scene and correlation analysis of it or part of it on the real scene.

In case of archaeological sites containing man-made objects the decision is of special interest whether image features are caused by deterministic or random scattering. Furthermore, detection of specular reflected signals might help to localize bright and long term stable pixels in SAR images which are used in Persistent Scatter Interferometry for detecting ground displacement in the range of millimetres per year.

Hence, for supporting the geometrical interpretation of spaceborne SAR images and for prediction of scattering effects expected in images to be acquired is generated a simulated image that is able to approximate the reflections appearing at objects at the ground. Knowledge about the satellite orbit is used for approximating the geometry of the imaging process that is the ancillary data of the real radar scene. Ray tracing algorithms are enhanced and adapted for following the signal within the model scene. Reflection effects are simulated in 3D, e.g. in azimuth, range and elevation. Hence, separation of several scatterers within the same resolution cell is enabled. The enhanced process is illustrated in figure 14 below.

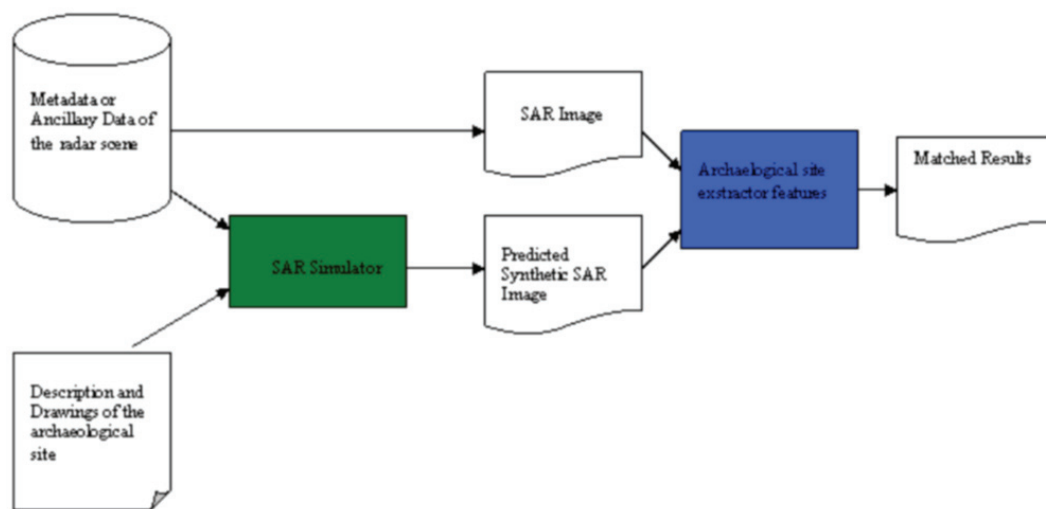


Figure 14. Data processing enhancement

The shape matching operator used in the visible images as defined in the previous activity is injected in the SAR simulator generating the simulated target. The search algorithm is then applied to the SAR images generating the detection file to be superimposed to the GIS maps.

For the actual tests two Cosmo SkyMed images of the Giza pyramids has been used (2 images have been used: one ascending and one descending) as seen in the picture below.

The target object has been extracted from a visual image already geometrically corrected (one of the Pyramid). The SAR simulator produced the distorted radar image (simulated target) and searched in the Cosmo SkyMed images using the shape matched operator.

Hereafter are depicted the three steps necessary to produce the predicted synthetic image.

The initial test has been successfully executed six times using two different templates extracted from visual images and simulated according the SAR images ancillary data.

This approach is proving that the current template matching algorithm is robust enough to work as well with radar images' providing the SAR simulator is used to produce the shape operator.

Further tests are still in progress involving other interesting issues that will be analyzed in the near future such as scale and orientation invariance and shadowing. These parameters are regarding both geometric and radiometric aspects and can make more critical the recognition of the searched pattern. Depending on the adopted algorithm, the performances can be affected as well.

In order to evaluate these latter considerations, it is important to see how much is adaptive the current recognition algorithm. Of course it is well known that a piecewise function can be expanded

by an orthogonal set of functions, but most of the capability to recognize some objects is strongly related to the expansion itself.



Figure 15. SAR shot of Egyptian Pyramids at Giza (*courtesy of ASI and E-Geos*)

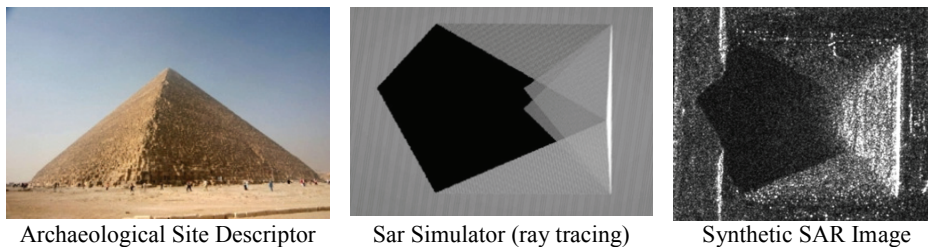


Figure 16. 3 steps detection for SAR images

In other words if the expansion coefficients are suitable for a large number of terms, the reconstruction of function can be achieved with high accuracy but with direct impact on the performances. So in this case it will play an important role the relative error between the input image and the reconstructed one, although recent studies have showed that the relative error can be reduced if the module of the complex discrete distribution is squared.

5. Conclusion

An application has been presented for the automatic detection of 2D shapes using a shape matched operator. The application has been developed to fulfill a service requirement of an End-user of EO data. Specifically, the application has been developed to monitor and identify lost or undiscovered archaeological structures in Egypt.

The approach used involves the use of historical cartographic data to provide shape information in order to automatically define a shape matched operator. The shape matched operator is applied to

appropriate EO images and the results of the shape detection are integrated into the GIS framework of the End-user.

An enhanced shape matched operator to take in consideration high resolution SAR images has been defined and the preliminary tests prove the methodology is mature enough. Further research and tests are ongoing in order to consolidate the methodology and improve the performance for automation.

A final validation of the methodology can be achieved using the same demonstration area used in HORUS pending the availability of the SAR data. This validation can enable the full development of a service case for monitoring of archaeological sites worldwide and specifically in the Mediterranean area where the great majority of them are located.

The algorithm is also suitable for detecting new archeological sites where some previous knowledge of the researched target (shape) is available.

Acknowledgment

Data for analysis of Saqqara and Fayoum archaeological site have been provided by architect A. Giammarusti of Pisa University, Italy. Cosmo SkyMed images of Giza Pyramids have been provided under courtesy of Italian Space Agency and E-Geos.

References

- [1] Moon H., Chellapa R. and Rosenfield A., Optimal Edge-Based Shape Detection, IEEE Transactions on Image Processing, Vol. 11, No. 11, November 2002.
- [2] Ben-Arie J. and Rao K. R., A novel approach for template matching by nonorthogonal image expansion, IEEE Trans. Circuits Syste. Video Technol., Vol. 3, pp. 71-84, 1993.
- [3] Di Iorio A., Bridgwood I., Rasmussen M., Sørensen M., Carlucci R., Bernardini F., Osman A., Automatic detection of archaeological sites using a hybrid process of Remote Sensing, Gis techniques and a shape detection algorithm, Proceeding of the 29° EARSel Symposium, Chania, Greece, in press.

