ADVANCES IN ON- AND OFFSHORE ARCHAEOLOGICAL PROSPECTION
Proceedings of the 15th International Conference on Archaeological Prospection

ICAP 2023

Identification of buried archaeological features using the curvelet transform

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Abstract

We present an application of the curvelet transform fusion method between geophysical and remote sensing data. The method was tested in two different archaeological areas in Greece with different historical, archaeological, and environmental characteristics. The final fused images combined all available information reducing the noise and enhancing the interesting features.

Introduction

Over the last decades geophysical methods have become a crucial part of the archaeological field exploration. All involved parts have recognized the importance of employing overlapping geophysical measurements with different methods as they deliver sensitivity to dissimilar subsurface properties, allowing a more robust and complete representation of the targets (Ernenwein and Hargrave 2007; Gaffney 2008). One common combination is the electrical resistivity with the geomagnetic gradiometry method. This is mainly to integrate the advantages of the resistivity in mapping targets such as building footings and other structural remains, with the sensitivity of the geomagnetic method to targets with substantial magnetic susceptibility e.g., ferrous metals, ceramic objects, and hearths (Kvamme et al. 2018). Additionally, remote sensing data have nowadays became a useful tool in archaeological research complimenting with data that provide easy access to even remote areas. Towards this direction, image fusion and in particular the curvelet-based fusion method (Karamitrou et al. 2019) allows the automatic integration of multiple overlapping datasets from various remote sensing methods, (e.g. Karamitrou et al. 2021) that delineate surface signatures of subsurface structures. In this work we demonstrate the advantages of this approach using data from two archaeological areas in Greece.

Method

Once the remote sensing images are acquired some basic processing is applied (e.g. arctan function, interpolation, dynamic range compression, high-pass filter, Wallis filter). While the data cover that same area of examination an additional fine co-registration is applied that further adjusts fine-scale discrepancies associated with inaccuracies mainly since the geophysical measurements are taken using hand-held devices as well as from errors in the relative positioning of the grids (Karamitrou et al. 2017). The next step is to apply the curvelet transform (CT) method where each image is decomposed (Candès and Donoho 2000) into discrete coefficients. These coefficients are functions of the spatial coordinates, scale (i.e. size), and azimuth of the imaged features. The CT is fully reversable and sparse. The main advantage of curvelet transform is that objects can effectively be represented as a series of smaller linear segments. The ability of the CT to distinguish the importance of imaged features according to their location, size, and orientation provides the means for an objective integration of different remote sensing images. The final fused image is created directly in the curvelet domain by comparing the corresponding CT coefficients of the initial input images and choosing the one with the maximum amplitude ("the maximum frequency rule").
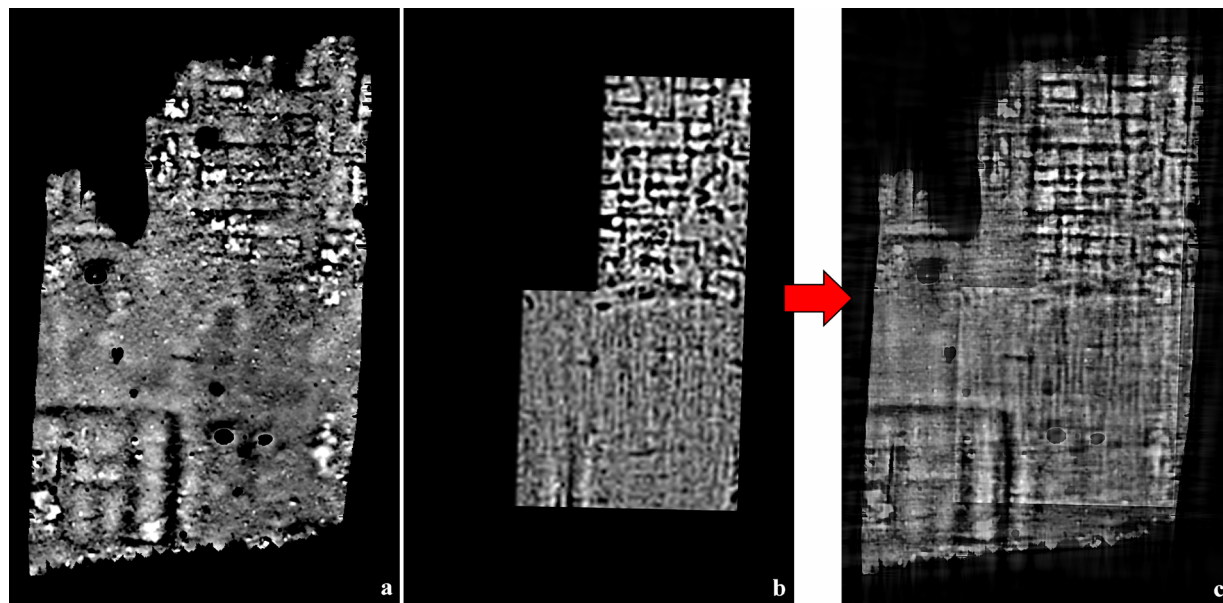
Fig. 1: Geophysical images from the area of Phillipi in N. Greece a) Magnetic gradiometry, b) electrical resistance and c) final fused image using the curvelet method.

Data

We applied the curvelet transform in two archaeological areas in Greece, the archaeological area of Philippi, located in Central Macedonia Region and the archaeological area of Stryme in Thrace. Each archaeological area represents a different era with different environmental and historical conditions. For the archaeological area of Philippi, we examined two geophysical methods (magnetic gradiometry and the electrical resistance) and one aerial image taken using a drone. On the other hand, for the archaeological area of Stryme, we have examined an image depicting the electrical resistance of the area and a GeoEye-1 panchromatic image with a resolution of 0.45 m.

Results

In both cases the final fused images represent the examined area in more details by enhancing the interesting features and suppressing the noise. From historical information and from excavations in the nearby locations of both areas of investigation we knew the orientation of the expected features. Therefore, during the fusion process we enhanced the images along these specific angles. Figure 1 shows an example from the archaeological area of Phillipi.

A visual inspection reveals that at the N-NE region where there are fine scale structures the resistivity image contributes more while at the SW region where longer wavelength features exist the magnetic image prevail. A further statistical analysis of the final fussed images allows the evaluation in more details. This analysis can be done efficiently on-the-fly during the fusion by keeping track of the number of non-zero coefficients that each image contributes to the fused product across different levels of the decomposition (i.e. scales) and angles (i.e. azimuths) (Fig. 2). This analysis reveals that the contribution of each image varies significantly over different scales and different orientations.

Conclusion

Image fusion is a powerful tool that enables the visualization of all available overlapping imagery into one single image. Archaeological images include complex features of various sizes and shapes and curvelet transform has proven to be a reliable method that manage to process these features as it can elevates a 2-dimensional image into a 4-dimensional space where instead of the two spatial coordinates the image can be expressed as a function of space, scale and orientation. In the final fused images, the noise is suppressed while the interesting features appear enhanced and, in many cases, more complete.
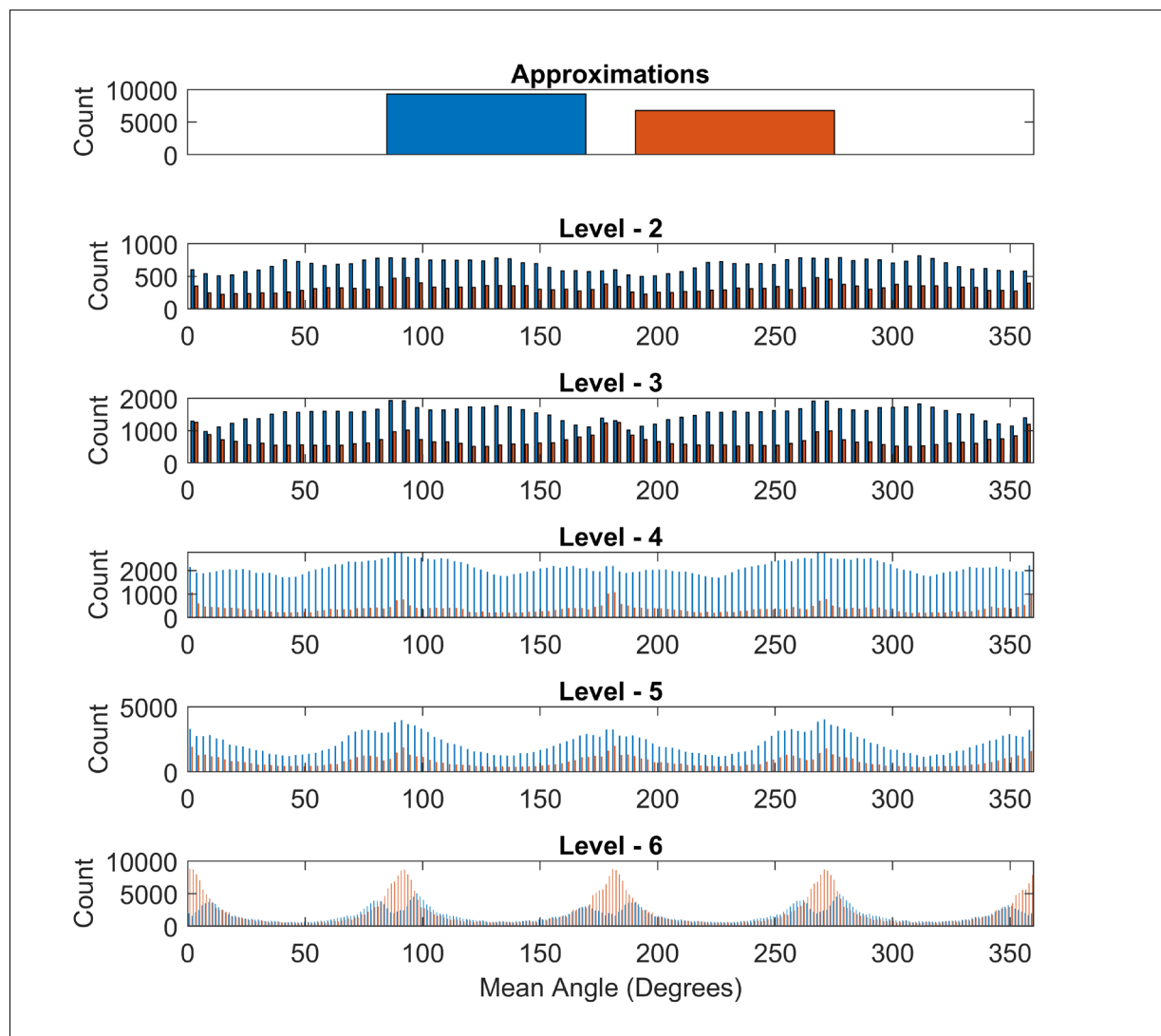
Fig. 2: Comparison of the contribution of the magnetic (blue) versus the resistivity (red) image to the fused product, along different levels and angles (azimuths). Vertical axes count the number of coefficients each image contributed. Top row shows the approximations, where no angular information is available.

Acknowledgments

References

Candès EJ, Donoho DL. Curvelets–a surprisingly effective non adaptive representation for objects with edges. In Cohen A, Rabut C, Schumaker L. Curves and surface fitting. Proceedings of the 4th International Conference on Curves and Surfaces, Saint-Malo, France, 1-7 July 1999, Volume 2. Nashville, TN: Vanderbilt University Press; 2000. p.105–120. Available from: https://apps.dtic.mil/sti/pdfs/ADP011978.pdf

Ernenwein EG, Hargrave ML. Archaeological Geophysics for DoD Field Use: a Guide for New and Novice Users. Washington DC: Environmental Security Technology Certification Program; 2007 Report for Project 200611. Available from: https://apps.dtic.mil/sti/citations/ADA596339

Gaffney C. Detecting trends in the prediction of the buried past: a review of geophysical techniques in Archaeology. Archaeometry 2008; 50:313-336.

Karamitrou A, Bogiatzis P, Tsokas GN. Fusion between Geophysical and Satellite images for the study of Archaeological sites. Archaeological Prospection 2020; 27:118-133. doi: 10.1002/arp.1766

Karamitrou A, Tsokas NG, Kaimaris D, Dadaki S, Stampolidis A, Vargemezis G, Tsourlos P, Fikos E. Joint Interpretation of Various Geophysical Data by Means of Image Fusion in Philippi in Northern Greece. ArcheoSciences - revue d'archéométrie 202; 45: 259-262. doi: 10.4000/archeosciences.9954

Karamitrou A, Tsokas GN, Petrou M. A Pixel-Based Semi-Stochastic Algorithm for the Registration of Geophysical Images. Archaeological Prospection, 2017; 24:413-424. doi: 10.1002/arp.1578

Kvamme KL, Ernenwein EG, Menzer JG. Putting all together: Geophysical data integration. Persico R, Piro S, Linford N, editors. Innovation in Near-Ssurface Geophysics. instrumentation, application, and Data Processing Methods. Amsterdam: Elsevier; 2018. p. 287-339. doi: 10.1016/B978-0-12-812429-1.00009-X