CAA 97

GPR Analysis and Modelling with GIS Applications, Empúries, Spain

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Abstract

GIS and statistical analyses of raw, scanned ground-penetrating radar data serve to assist in the computer determination / identification of sub-surface features. Time slice interpolation and the interpolation of standard deviation activity maps have successfully imaged prominent repeating anomalies across several parallel profiles reflecting man-made features. Thorough analysis of the 95 surveyed radar transects the nature of sub-surface features will be revealed and subsequently assigned an ethnic identity. Terms: ground-penetrating radar, time slice, standard deviation "activity maps"

1 Introduction

During June of 1996 Boston University conducted a student field school at Empúries, Spain. Empuries is an important archaeological site spanning from the 6th century BC to the second century AD. Located on the northeastern coast of Spain in the area of Catalunyia, Empuries boasts a combined occupation of indigenous and Greek residents with later Roman settlement. Around 575 BC, Phocaean Greeks branching out from Masallia, modern day Marseille, settled at Palaeopolis, on a small island at the mouth of the river Fluvia. After developing into a major port and exchange centre, the Greek population of Paleopolis expanded to the mainland across from their island city to a settlement called Neopolis. Roman occupation began to the west of Neopolis in 278 BC with the establishment of a military garrison. The first and second centuries BC saw development of a more civic nature, and which expanded to enclose Neopolis within defensive walls. During this period the site took on the Latinised name of Emporiae, or market. Late first century AD saw the silting of the Fluvia river course and the decline and abandonment of Empúries. (Harrison 1988)

According to first century AD authors Livy and Strabo, Greek colonists lived side by side with the indigenous population of this area, the Indicans. (Livy: 34.9.4 - 9.4, Strabo: Geography 3.4.5 - 9). The modern-day parking lot of the site was targeted in the early 1980's in an attempt to locate the reported Indican village of Indica. Excavation revealed 4th and 3rd century BC burials with mixed Greek and Iberian amphorae, a 2nd century unidentified structure, and two subsequent phases of Roman metal working structures. No positive identification of indigenous occupation was discovered during this work, and no positively identified Indican structures were found elsewhere on the site. (Sanmarti et al. 1983-1984)

As part of a larger study investigating the interaction of the indigenous and colonial populations at the site of Empúries, the parking-lot of Neopolis was selected for geophysical survey in an attempt to establish the presence or absence of an indigenous settlement. Ground-penetrating radar was selected as the most suitable geophysical method for investigation. Ever present cars, fences and ferrous debris, and a lack of ground moisture ruled out magnetic and resistance survey.

The ground-penetrating radar survey was conducted as part of a student field school run through Boston University. A GSSI Sir System 3 radar unit with 300 and 500 MHz antennae were used. Data was recorded on paper scrolls. Grids surveyed in the parking lot bordered the previous excavation of the 1980s. 20 to 40 m transects, with 1 m spacing, were oriented on a north-south axis with east-west intersections at points of interest. This paper presents an attempt at interpretation of seven, 20 m transects on the eastern edge of grid 3.

The basic premise of radar interpretation is the recognition and identification of repeating anomalies across profiles which are interpreted as reflecting man-made or geological features. Through detailed manual interpretation or computer processing these repeating anomalies can be identified and imaged in horizontal site plans. Different methods of analysis were applied in the investigation of the contents of our data. Initial in-field viewing and traditional box grid construction of paper profiles revealed significant repeating anomalies. Recent research however, allowed the interpretation of these data using a more up-to-date methodology. Consequently, all paper profiles were digitally scanned and converted into digital imagery.

2 Data Interpretation and GIS

The developing field of computer applications and quantitative methods in archaeology directly contributes to the processing of radar data. The nature of the data presented here forces one to look beyond simple visual and manual analysis of black and white profiles for the identification of prominent anomalies. In order to remove the data from an interpretative process based on experience, preconceived ideas, and prejudices and toward more objective results, a series of visual and statistical processes were applied to the data in order to provide feature identifications with a more substantial basis. In order to accomplish this, several Geographic Information Systems (GIS) tools and simple variance statistics were employed, and the initial results are presented here.

3 Rectification

As everyone who has used radar in the field knows, different people pull antennae at different rates. Radar profiles were collected by a number of students, thus the profiles vary in drag rate and spacing between meter marks. Along with intermittent use of the 300 and 500 MHz profiles, the data is quite irregular.

In order to rectify spatially each profile so they can be submitted to further analysis, scanned profiles were processed within Idrisi. This GIS allowed for cropping of profiles at designated row and column co-ordinates and stretching each cropped image in order to create final images of each designated radar profile of the same size and resolution. Once resampled, the temporal axis of the profiles was converted to depth. As the survey area surrounded an open excavation, transects were run along exposed balks which permitted measurement of the depth and nature of subsurface features. (Fig. 1)

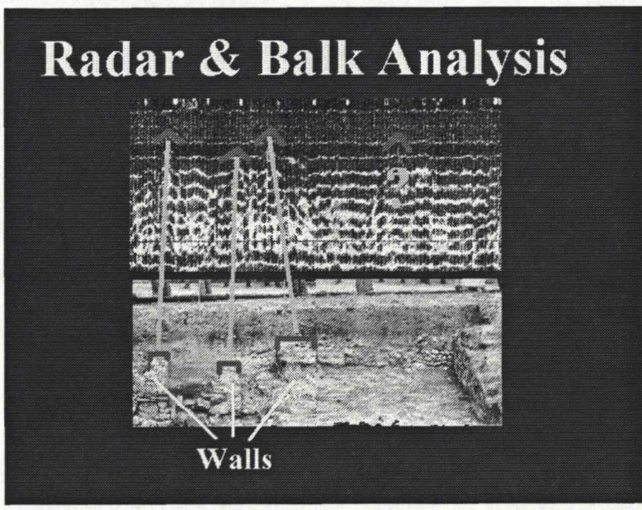

Figure 1. Baulk profile comparison

4 Image enhancement

GIS operations assist in the further investigation of geophysical data through the enhancement of imagery via contrast enhancement, false colour display, data interpolation, and filtering. These processes tend to emphasise trends running throughout the data.

5 Time slice analysis

Profile stacking is an initial step in the process for the recognition of repeating anomalies. Following the idea of Goodman, Nishimura, and Rogers (1995), isolation and concatenation of time slices in parallel profiles provides continuous data for a specific time and, later, a calculated depth for the survey area. A designated number of rows of data are isolated from each radar profile at a specified time (or depth). These rows are kept in the same order and pasted together in an image. (Fig. 2)

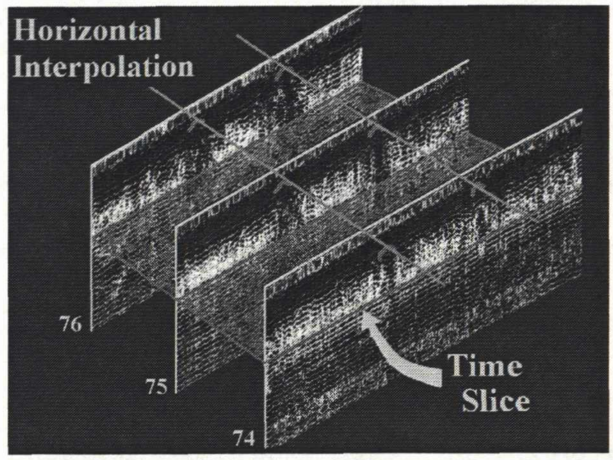

Figure 2. Time Slice interpolation

This image can be viewed orthographically (Fig. 3), which graphs the values of each column in its respective isolated row. Orthographic display of isolated time slices assists in manual identification of repeating trends in parallel profiles.

Another step, away from manual interpretation, is through interpolation of the isolated rows of information. Interpolation through GIS normally performs a two dimensional search for surrounding values in order to determine connecting surfaces. This process cannot be applied to the present data as it consists of parallel rows of information, making only a one-dimensional search possible. Initial interpolation of raw data appears extremely striped but can be smoothed through repeated filtering. This process produces a horizontal plan of the survey area.

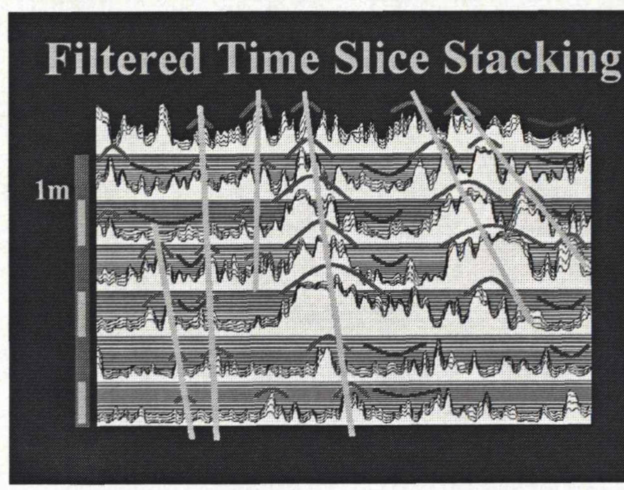

Figure 3. Orthographic time slice display

6 Variance statistics

As utilised by Fletcher and Bradley (1995), application of variance statistics to radar profiles also assists in anomaly and feature identification. Variance statistics show particularly active or rapidly changing areas in radar profiles which tend to correlate with significant anomalies. A special purpose program was written to determine the standard deviation and mean values of each profile in our study area. Calculations were performed on groups of 5 image columns, representing intervals of 20 cm on the ground, within the image representing 500 columns, or 20 m transects. The final file is reduced to a single row of 100 columns representing activity, obtained through the calculation of standard deviations, for each 20 m transect.

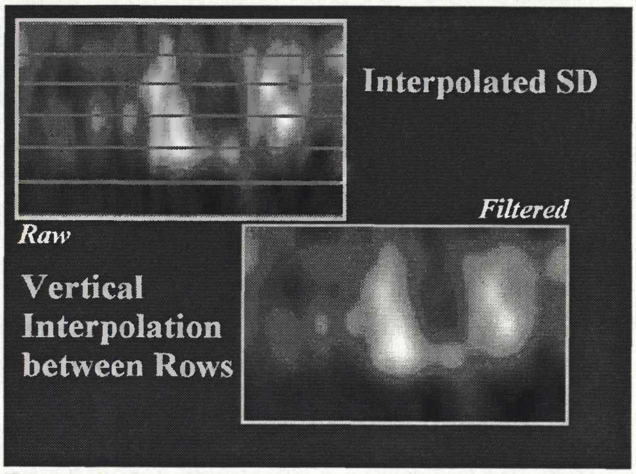

Figure 4. One dimensional interpolation

The resulting transects, pasted in order, can be viewed orthographically as with the time slice analysis. One dimensional interpolation (Fig. 4) can also be performed to generate a horizontal image of profile activity.

7 Conclusions

Despite the fact time slice analysis and calculated variance "activity maps" represent different data, they both reflect the same prominent trend which runs through each radar transect. Thus, we can conclude that, aided by GIS operations of image rectification and enhancement, both time slice interpolation and "activity analysis" in radar transects can be used to create horizontal plan views for given data. (Fig. 5) Through this process we are able to investigate, not only the presence of significant anomalies, but are able to trace their depth and changes in the site.

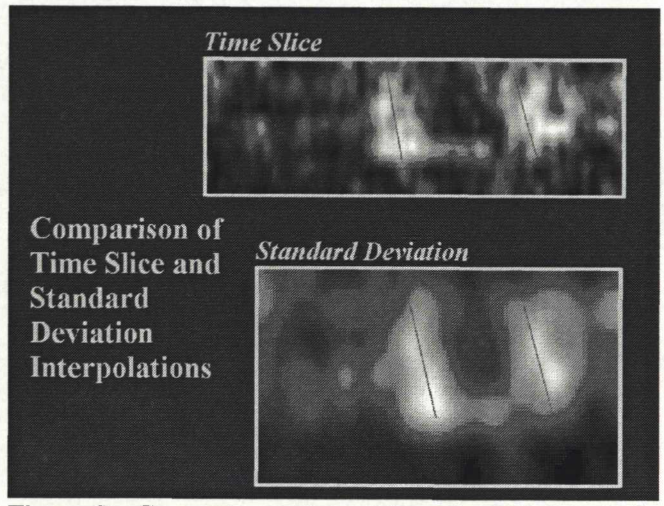

Figure 5. Comparison of one dimensional interpolation of time slice and standard deviation analyses

The application of GIS functions and statistical analyses in this case clearly reveals a substantial sub-surface feature which was identified as two parallel walls running for 5m in an east west orientation. Based on excavation baulks, these walls are probably 50 cm in width and situated at a depth of 1 to 1.5 m below the surface. These results suggest a continuation of the complex of Roman metal working installations, revealed during the parking lot excavation of 1982.

Acknowledgements

I would like to thank Dr. Kenneth Kvamme for his input to this paper in the form of good advice as well as allowing me to use his programs Colvar I, Colvar II, and Terrpac.

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