

Multi-scale analysis and interpretation of multi-method geophysical data sets

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Abstract

Redundant wavelet transform is proposed to analyze multi-method databases. Multi-scale analyses are used to separate target features from noise and background. As a main result, we generate composite images optimized for complementary information.

Keywords

archaeological prospection; composite imaging; multi-method approaches; multi-scale analysis; wavelet transform

Introduction

In archaeological prospection, the benefit of multi-method geophysical exploration strategies is well known. The basic idea of collecting multiple geophysical datasets across the same field site is to sense different medium properties and, thus, to collect complementary information. To ease the analysis and interpretation of such multi-method databases different approaches have been proposed (e.g., Kvamme et al. 2019). One popular group of approaches relies on integrated visualizations using transparent overlays and color blending. Here, the individual datasets are typically pre-processed to suppress random and acquisition-related noise. Furthermore, we have to consider the resolution capabilities of the involved methods which depend on subsurface parameter contrasts, target depths, and sensor configurations. Thus, a typical multi-method database comprises datasets showing anomalies at multiple spatial scales with different noise, sensitivity, and resolution characteristics. To analyze such a database and to generate optimized composite images, we present a multi-scale approach based on a redundant wavelet transform. After briefly discussing the methodological basics, we present a case study where we use the proposed strategy to analyze magnetic, electromagnetic (EM), and topographic data in an integrated fashion.

Materials and methods

Our approach relies on a redundant wavelet transform (RWT) which allows for an undecimated multi-scale decomposition of a dataset. Using a series of low-pass filters, the selected RWT iteratively decomposes a given data set a_0 into n wavelet planes w_j ($j = 1, \dots, n$) and an approximation a_n (Starck et al. 2015). Such redundant transforms (i.e., the size of all w_j is equal to the size of a_0) are preferred in applications aiming at reconstructing an image. For example, for filtering we reconstruct a filtered dataset using selected w_j to highlight features at specific spatial scales (similar to a wavenumber-domain filtering). Following Tronicke et al. (2020), we may also use scaled and normalized w_j to balance the contributions of selected planes in the reconstruction (similar to spectral balancing approaches).

Here, we use the RWT to analyze magnetic and EM data collected in 2012 across a well-known Neolithic ring ditch system (Lück and Eisenreich 1999) using a cesium gradiometer and an EM38 device, respectively. Both datasets were kinematically recorded with an in- and cross-line point spacing of ~ 0.1 m and ~ 0.5 m, respectively, using an auto-tracking total-station for positioning. This also resulted in a digital terrain model (DTM) of the surveyed area. Figure 1 illustrates our raw database after interpolation to a grid with a regular node spacing of 0.2 m. We used the RWT to decompose our datasets up to $n = 8$ scale levels

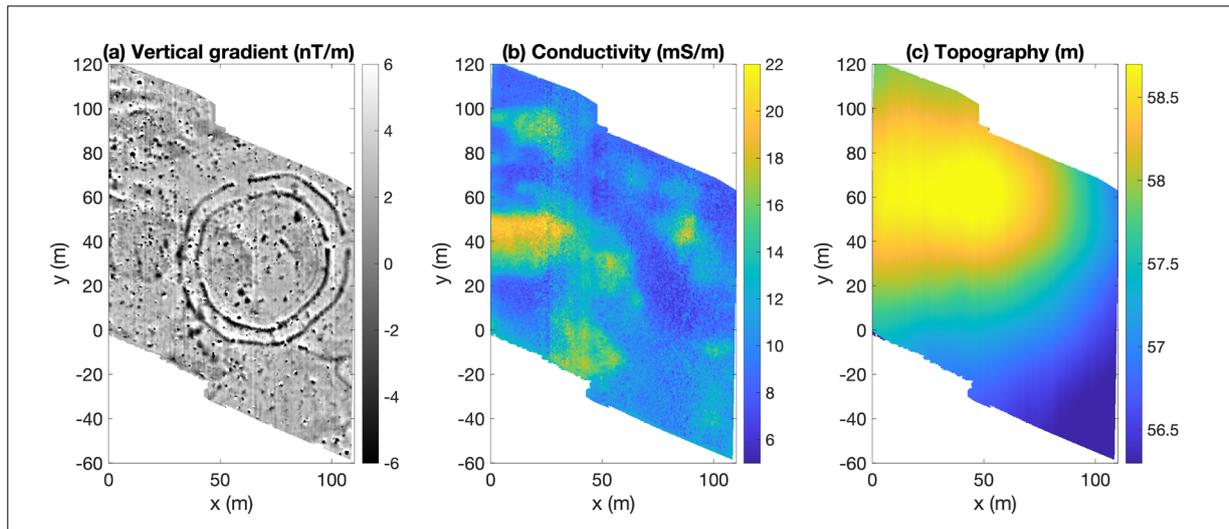


Fig. 1: Raw datasets consisting of a) vertical magnetic gradient, b) electrical conductivity, and c) DTM.

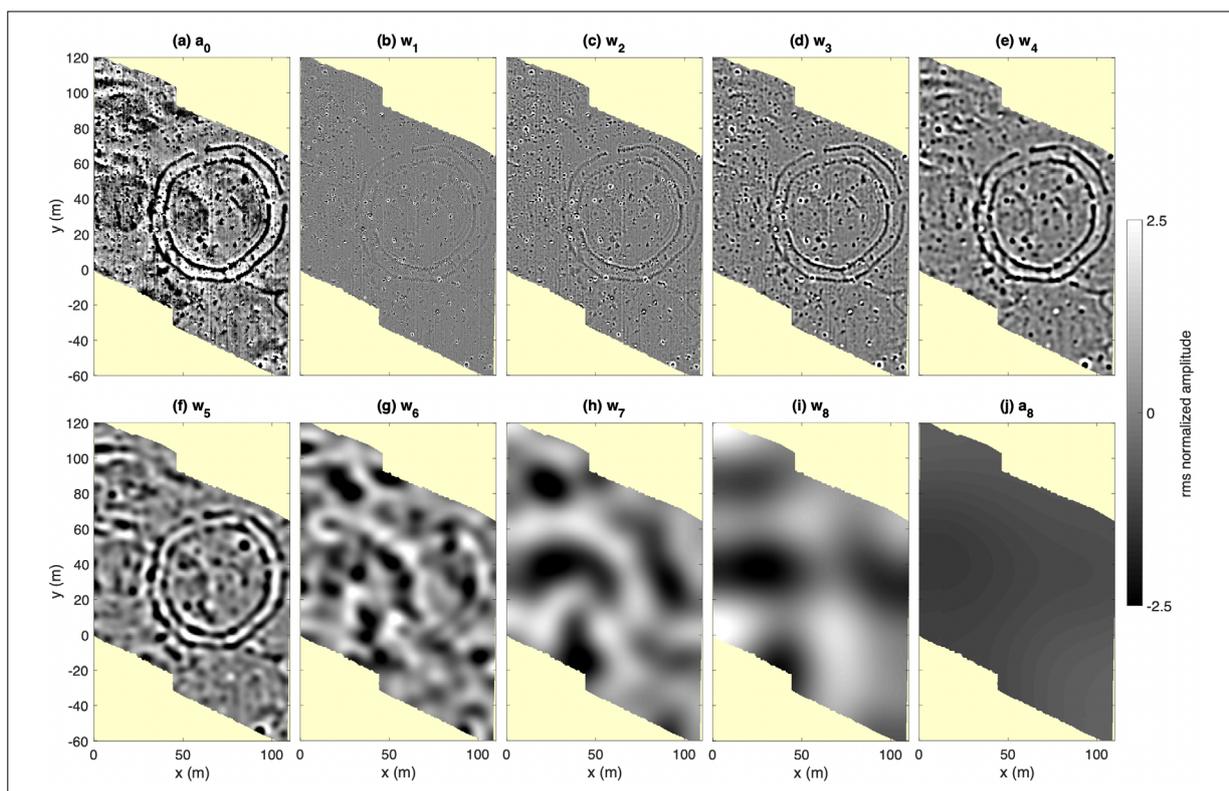


Fig. 2: Result of decomposing the magnetic dataset (Fig. 1) up to $n = 8$ scale levels. a) Input data a_0 , b-i) the resulting wavelet planes w_1 to w_8 , and j) the final approximation a_8 .

for a scale-dependent analysis of noise and anomaly features. We also quantified similarities by calculating pairwise correlations coefficients r between the normalized images at all scales. Finally, the (dis-)similarities between

the images were interpreted in terms of archaeological relevance to identify complementary information in our database and to create optimized composite images using selected scaled wavelet planes.

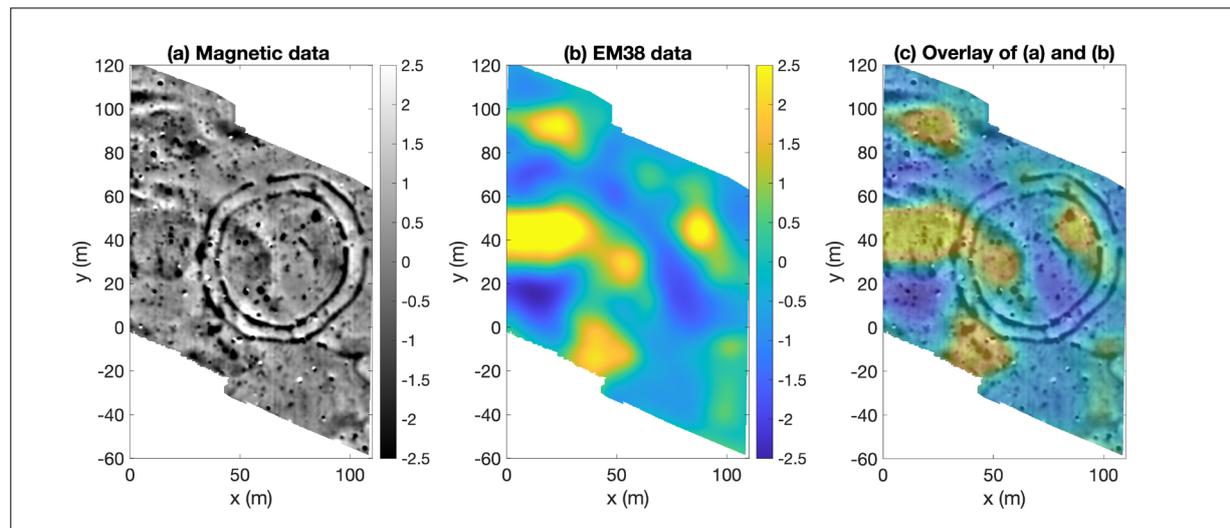


Fig. 3: a) Magnetic image reconstructed using wavelet planes w_3 to w_6 , b) EM image reconstructed using wavelet planes w_6 to w_8 , and c) composite image of a) and b).

Results and discussion

In Figure 2, we present the decomposition of our magnetic data. For balancing, all images are normalized by their individual root-mean-square (rms) amplitudes. Comparing these images illustrates that w_1 and w_2 are dominated by isolated and stripy patterns (interpreted as noise), while w_3 to w_6 show pronounced circular structures (interpreted as the Neolithic ditch system) and further curvilinear features (with potential archaeological relevance). Furthermore, w_7 , w_8 , and a_8 show anomalies with lateral extensions of > 20 m (interpreted as geological background). To analyze these observations in more detail, we compare Figure 2 to our EM and topographic data (Fig. 1) including RWT-based decompositions of these datasets (not shown here) and calculate r between all datasets. These analyses demonstrate that our magnetic data are independent of topography ($r < 0.35$ for w_1 to w_8), while we observe some links between EM and topography ($r > 0.5$ for w_5 to w_8). At lower scales, where we expect archaeologically relevant structures, magnetic and EM data are uncorrelated ($r < 0.3$ up to w_6), while at higher scales, reflecting the geological background, we observe negative correlations ($r < -0.6$ for w_7 and w_8). Considering these observations, we generate denoised composite images optimized with respect to the complementary information. Figure 3a) shows a magnetic image reconstructed using the rms-normalized planes w_3 to w_6 (Fig. 2) to highlight archaeological structures, while Figure 3b) is reconstructed with the rms-normalized

planes w_6 to w_8 from our EM data to characterize background structures. Because these images are not correlated ($r = -0.14$), the overlay image (Fig. 3c) represents an optimized starting point for further, more detailed interpretations.

Conclusion

Multi-method geophysical surveying is increasingly used in archaeological prospection. Typically, the gathered datasets show noise and anomalies at multiple spatial scales and are characterized by different resolutions and sensitivities. The proposed RWT-based strategy addresses these characteristics and, using a case study, we have shown that our approach results in composite images optimized in view of complementary information and, thus, detailed interpretations. Because our approach is computationally efficient and needs no parameter tuning, the presented strategy represents an efficient multi-scale approach for analyzing different combinations of geophysical datasets. —

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