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*Short Paper*

# Visualization of ERT Data for Archaeological Purposes

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## Abstract

*This work presents a visualization methodology for the correct comprehension and interpretation of ERT data by archaeologists. The authors developed a methodology based not only in colour mapping and slicing techniques but also on contouring and interaction procedures, obtaining an alternative to the traditional 2D pseudosection data visualization workflows.*
*The implementation was carried out with the Visualization Toolkit from Kitware Inc. and is illustrated using two data samples: the first one was obtained on a hillfort in Boticas (Portugal) and the second one was acquired on an urban archaeological intervention in Braga (Portugal).*

## CCS Concepts

•***Human-centered computing*** → *Visualization;* •***Computing methodologies*** → *Volumetric models;* •***Applied computing*** → *Archaeology;*

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## 1. Introduction

The archaeological excavation is an unrepeatable procedure [Bar77]. Thus, the guiding principles established by European agreements about Heritage recommend that an archaeological intervention on a site should always have the least possible impact. To minimize such impact, it is suggested to use non-destructive methods whenever possible, and that excavations are only to be carried out when there is a solid scientific basis justifying them or in case of imminent risk of Heritage loss. But even in such situations, a total and absolute intervention on the archaeological site should be avoided [ICO17] [oE17]. Archaeology teams take these recommendations seriously and integrate multidisciplinary techniques into their daily practice to study, in an indirect way, the archaeological potential of a given site. Geophysical techniques are used by archaeologists to evaluate features regarding a non-visible reality (the subsoil) in a non-intrusive way.

Archaeology and Geophysics deal with the opacity of the subsoil data used in each of their specific scientific horizons. Earth Resistance Tomography (ERT) is a geophysical survey technique in which the resistivity data obtained are analysed by inversion techniques and then processed by imaging tools, in order to obtain a scalar model that can efficiently represent the near surface resistivity distribution patterns. While using ERT, archaeologists seek to understand the geophysical data by analysing the scalar models and detecting anomalies that might relate to archaeological features. But, both the raw data and the visualization models are not understandable in a user-friendly way, and most archaeologists will have some difficulties understanding the data and its visual output. Therefore, an appropriate visual enhancement of the dataset is required for better insight. This work proposes a methodology that allows archaeologists to visualize the data obtained from the ERT survey in a simple, interactive way, enhancing its readability and understanding. In this sense, clusters are defined that represent potentially significant data for archaeological purposes. Due to the specifics of an ERT geophysical model, the output are not geometric surfaces that replicate the accurate form of what is hidden in the subsoil, but an enhanced contrast produced by a dissonant feature in its surrounding physical context.

The next section will briefly contextualize the use of Geophysical surveys in Archaeology and explain how the traditional visualization process occurs. The third section explains the proposed visualization workflow and the techniques used to efficiently represent the surveyed data to archaeologists. Two visualization examples are presented in the fourth section, regarding two distinct archaeological contexts. At the end some conclusions are presented as well as the authors' intention regarding future work.

## 2. Geophysical Survey in Archaeology

The development of geophysical survey techniques with applicability in archaeological context has been intense, particularly regard-

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ing methods like Ground Penetrating Radar (GPR) [Con06] [GP13] [TTL*14] and ERT [Pir08]. However, there are other survey techniques which are also used in archaeological fieldwork such as magnetometer, electromagnetic and topsoil magnetic susceptibility survey [Dav08]. All those techniques are to be used in different scenarios and selecting the suitable survey option (or options) might not always be an easy task [Dav08].

The archaeological conclusions from geophysical surveys are always indirect, since what is measured is the response of physical components when exposed to a physical process or phenomenon. The archaeological feature, if present, will cause a dissonant reading, because it usually introduces a large alteration over the natural processes of deposition in its surrounding context. In the case of Electrical Resistivity, the data measurements (Ω/m) used to create a representation model of the initial observed parameters, represent an Inverse Problem. In the 90's, the computational resolution of this mathematical problem led to the possibility of a tomographical view of the geophysical model [Pir08] [Lok17], making possible for this data to be analysed by imaging techniques, such as image-based modelling.

In its common way, resistivity data obtained from a geophysical survey results from 2D linear profiles, where the readings are collected by a multi-electrode array. The underground contexts surveyed are always heterogeneous and anisotropic, but the best way to get a 2D profile model is through apparent resistivity, where the physical behaviour is modelled as if they were homogeneous and isotropic. The pseudo-section resulting from a 2D profile of electrical resistivity represents an approximate image of the resistivity distribution, in relation to the selected array [Lok17] (see figure 1).

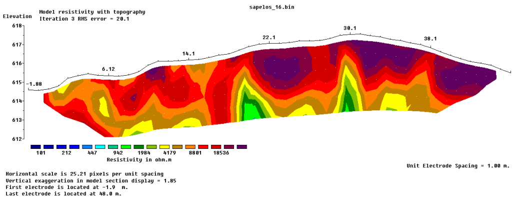

**Figure 1:** *Inverse model pseudosection of the profile 16 surveyed in Sapelos Hillfort, modeled with topographical correction*

## 3. Visualization Workflow

3D visualization of geophysical survey data is not a recent subject. There are authors who have already addressed this issue [Wat06] [KEH*09] [NLN09] [LNW*11] [MLF*13]. However, the aim of this work is not only to focus on the accurate visualization of the surveyed data, but also on the archaeologists' needs for understanding the geophysical survey. The current methodology generates volumes of interest which, due to their geometric nature, are more easily used in archaeology. Figure 2 shows the steps leading to the creation of representative clusters with potential archaeological interest.

The data of an ERT survey are of three-dimensional nature, where each 3D point is georeferenced and has an additional associated attribute that represents the resistivity. These unstructured points do not have any topological relation between them but are grouped in a uniform point cloud. The density of this grid depends on the inter-electrode spacing during the survey, which is adjusted for each site.

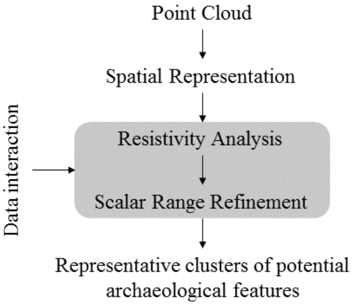

**Figure 2:** *ERT survey visualization workflow*

### 3.1. Spatial Representation

The first stage of the visualization workflow is the pre-processing step where the goal is to create a perceived representation of the 3D point cloud. This pre-processing is necessary to understand the spatial extent of the ERT survey and also to create topological relations between the points. Therefore, an efficient approach is to use a triangulation technique that simultaneously establishes a topological relation between the unstructured points and produces a tetrahedral mesh representing a volume.

An appropriate method is the 3D Delaunay triangulation [Bow81] [Wat81], not only because it produces sound topological relations between the points but also because the resulting triangles are well shaped with large internal angles, which is an important feature for balanced data rendering. Another functional method is to resample the data into a volume representation, based on the scalar values.

### 3.2. Resistivity Analysis

The resistivity analysis follows in order to visualize the distribution of the scalar resistivity values over the spatial representation of the point cloud. This will allow the user to comprehend the overall range of resistivity values and to realize its distribution.

An immediate way to visually understand how resistivity is distributed is by associating the range of resistivity values to visual properties, such as colour and opacity, of the point cloud's 3D representation (see figure 3). This can be done using colour and opacity lookup tables, to map the resistivity range to colour and opacity values, respectively.

### 3.3. Scalar Range Refinement

After performing the resistivity analysis, the user will have a visual understanding of the ERT survey. However, it is still necessary to select the scalar range which is potentially useful for archaeological purposes. This is necessary to create clusters that represent

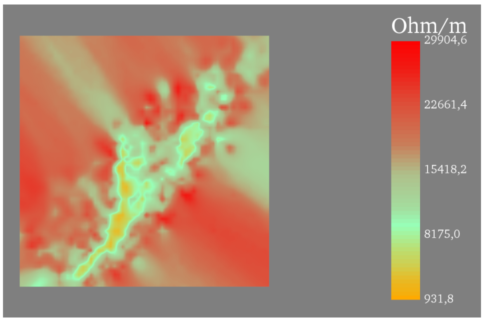

**Figure 3:** *Scalar Distribution over the Volume Representation*

potential archaeological features and will enhance the user's visual perception regarding the geophysical survey (see figure 5). The range of interest is provided by experts, according to their knowledge regarding environmental variables (soil moisture, climatology, geotechnics and mineralogical characterization) and taking into account the existence of historical structures and evidences.

Once the scalar range of interest is defined, there are two complementary approaches to outline the clusters of prospective interest. The first one is based on colour and opacity lookup tables, while the second uses contouring techniques. Essentially, this second technique generates 3D boundaries (isosurfaces) representing a constant scalar range. These boundaries delimit the geometry of the clusters with potential interest for archaeology and are independent from the initial volume.

### 3.4. Data interaction

The free manipulation of the data is important. Therefore, data interaction procedures were designed to act on the processing steps (resistivity analysis and scalar range refinement stages) to enhance the understanding and identification of the data features, not only on the volume's surface but also on its interior.

Besides the common mouse-based interaction techniques, such as rotation, panning and zooming, a 3D widget to interact with the interior of a volume (figure 6) is also available. The 3D widget does not manipulate any data but it is used to alternate between the two approaches used for outlining the clusters.

### 3.5. Development

There are several systems currently used for visualizing geophysical data, either commercial or open-source. However, this visualization methodology is based on the *Visualization Toolkit* (*VTK*) from Kitware Inc. [SML06]. In the current application, the data visualization and interaction mostly use the available VTK functions.

For the pre-processing two distinct *VTK* modelling techniques were used for visualizing the unstructured points. On the one hand, the 3D Delaunay triangulation class (*vtkDelaunay3D*), which outputs the tetrahedral mesh as an unstructured grid dataset. On the other hand, Shepard's method (*vtkShepardMethod*) to sample the 3D points onto a volume dataset. Both techniques can be used separately or in a combined manner.

The processing phase uses several filters in both stages. For the colour mapping the lookup table is represented as a colour transfer function (*vtkColorTransferFunction*), while the opacity lookup table is defined with the *vtkPiecewiseFunction*. The definition of both transfer functions is not a minor issue and presupposes a truthful understanding of the scalar values since the effective volume visualization depends on it. In fact, after defining the scalar range of interest, only the values inside the range are set completely opaque. The contouring, which creates the 3D surfaces from the resistivity values that correspond to anomalies of interest, is performed with the *vtkMarchingContourFilter*.

To interact with the interior of a volume it is necessary to combine a filter that uses a plane (*vtkPlane*) to clip polygonal data (*vtkClipPolyData*) with a 3D widget that is able to interactively move a plane (*vtkImplicitPlaneWidget*) over a 3D object. By moving the implicit plane widget, the user can interactively determine what is visible on both sides of the plane.

## 4. Visualization Results

This visualization methodology was applied to two distinct archaeological sites where an ERT survey was carried out by the same team and using the same survey procedures. The first site is a fortified settlement occupied during the Iron Age, known as the Sapelos hillfort and located in Boticas (Portugal), outside the urban perimeter. The other site has been occupied since the Roman Period, integrates the urban landscape of Braga (Portugal) and is located inside the Seminary of São Pedro e São Paulo.

Each site has different ranges of resistivity values that represent everything that can be found beneath the surface. However, for archaeological purposes it is necessary to set a range of resistivity values of interest which might relate to archaeological features.

During the survey of the Sapelos hillfort, values of resistivity between 146,03 Ω/m and 1.586.377,75 Ω/m were processed. But the values of interest for archaeological purposes range between 24.000 Ω/m and 25.000 Ω/m. The Seminary of São Pedro e São Paulo has different soil conditions and therefore the resistivity values have to differ also. Here the resistivity values vary between 44,2 Ω/m and 77.604,3 Ω/m and the subset of interest ranges between 100 Ω/m and 3.000 Ω/m.

### 4.1. The Sapelos Hillfort

The ERT survey was carried out over a linear grid with an $X$ parallel offset distance of $4m$, intersected by $Y$ distal lines equally spaced by $10m$ (see figure 4). The geophysical team used a *SYSCAL R1 Plus* (*IRIS Instruments*) resistivity meter and a total of 72 electrodes for an inter-electrode linear spacing of $1m$ to perform the survey. The Wenner-Schlumberger array configuration was assumed for measuring purposes and the data were processed with *RES2INV*, using the inversion algorithm based on the smoothness-constrained least-squares method.

In figure 5 it is possible to see a simple visualization of the imported ERT dataset after setting properly the scalar values of interest between 24.000 Ω/m and 25.000 Ω/m. This visual representation uses the volume-based approach and even less experienced archaeologists recognize straightaway some volumes of interest that

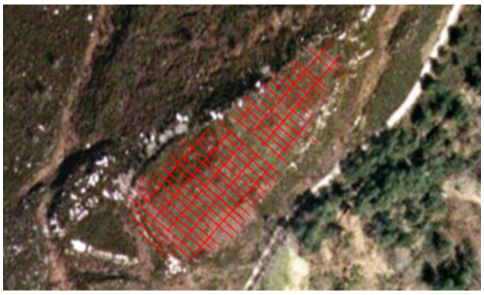

**Figure 4:** *ERT survey grid for the Sapelos hillfort*

possibly are associated to archaeological features. The user can immediately recognize the enhanced volume that bounds the surveyed area more precisely and also smaller volumes that represent clusters of resistivity values with potential archaeological interest. The representation can be freely manipulated around all axes.

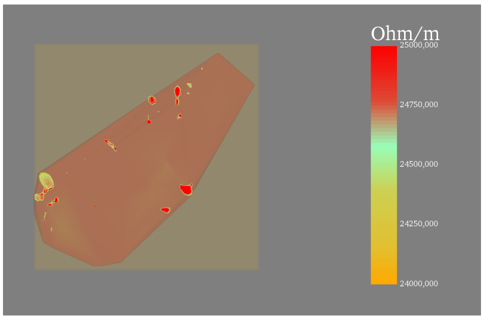

**Figure 5:** *ERT data Visualization of the Sapelos Hillfort*

The next stage uses the contouring filter to cluster the scalar range of interest into 3D surfaces. To do this, it is necessary to trigger the interaction widget that will sweep through the volume representation and simultaneously starts the contouring filter. After activating the widget, the volume will be highlighted with a bounding box and the sweeping plane will be visible, as well as its normal vector. Moving the plane freely over the volume will expose the clusters (in grey) that represent volumes of interest (see figure 6). It also augments the perception of much smaller volumes that are within the threshold condition, but that were not entirely perceptible in the colour mapping method.

### 4.2. The Seminary of São Pedro e São Paulo

The survey at the Seminary of São Pedro e São Paulo benefits from the experience gained at the Sapelos hillfort. The resistivity acquisition was projected on 18 latitudinal X-axis profiles, with equidistance and inter-electrode spacing of 0,5*m*. The survey was executed with the same resistivity meter using a multi-electrode scheme composed by 50 electrodes and the Wenner-Schlumberger array configuration for measuring purposes.

The intervention carried out at the Seminary of São Pedro e São Paulo occurs in an urban environment and in a private space. Thus, there are some constraints to the archaeological activity which naturally condition the geophysical survey. Also, the resistivity values of interest which are possibly related to archaeological features are different from the previous site. However, the described visualization procedure can be still used in this case, by adjusting the scalar range values (see figure 7). Clearly it is possible to understand where it is highly plausible to find some kind of structure which might be an archaeological evidence.

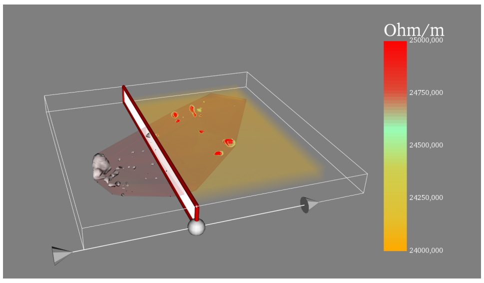

**Figure 6:** *Using the interaction widget horizontally to expose volumes of interest*

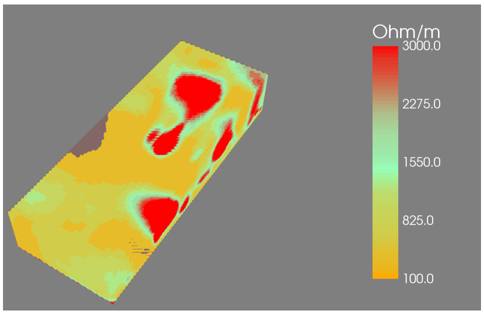

**Figure 7:** *ERT data Visualization of the Seminary of São Pedro e São Paulo*

## 5. Conclusions

The presented examples revealed that the usage of ERT data processed with 3D visualization methods is a valuable tool to enhance the analysis of the data and help the archaeological analysis for a given site, since they increase the readability of the geophysical data and some clusters were coincident with archaeological structures. Furthermore, given that the surveyed data are georeferenced, the geometric surfaces obtained during the visualization process can be exported as a geometry file and integrated with 3D cartography to plan an archaeological intervention.

This methodology can be applied to other geophysical survey data, provided the data are in the form (x, y, z, $\alpha$), where $\alpha$ represents any geophysical scalar measure. A small test with magnetic survey data was already performed and GPR data should also be tested in a near future.

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