# Geophysical archaeological prospection, the road ahead ...

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**Abstract**
We provide an overview of challenges and possible promising developments that lie ahead in the field of archaeological geophysics. The presented ideas can serve as blueprints for exciting new developments.

**Keywords**
archaeological prospection; future perspectives; technological and methodological innovations

## Introduction

Having seen a dramatic increase in coverage rates in the field of geophysical archaeological prospection as well as data density through the introduction of motorised prospection array systems (magnetometer, GPR, EMI) over the past decade (Trinks et al. 2018), the question arises, what will be the next exiting and promising challenges for research and development? In line with the three "S" stated by Helmut Becker at a workshop in Grossetto in 2006 regarding possible advancements in the field of magnetometry (Becker 2009), i.e. increased Speed, Sampling density, and Sensitivity, there exists still ample space for methodological and technological advancements of geoarchaeological prospection. While application case studies with increasingly larger survey areas – and thus greater chances of detecting interesting buried anthropogenic or natural anomalies – are becoming more common, the methodological and technological advancements of the discipline, with few exceptions, still seems to be mainly driven by the industry and geophysical prospection system manufacturers, through availability of new sensors and survey devices. Particularly in exploration or rescue archaeology, but as well in archaeological research projects, geophysical prospection still suffers from the inherent drawback that the relationship between archaeological structures buried in the subsurface and their expression in form of anomalies in geophysical prospection data is still not fully understood. Geophysical archaeologists are still mostly confronted with the situation that they would need to – and mostly want to – survey larger areas than time and funding normally permits, in order to properly understand the archaeological situation, site or problem. Even the ability to gather five hectares of high-resolution ground-penetrating radar data over the course of two days, at not insignificant cost, will not reveal the structure of a 50-60 ha large settlement, and thus inhibit a comprehensive understanding of a site. There exists still an urge to be able to collect ever more data across huge areas. At the same time, technological advancements in unrelated fields offer exciting new opportunities for collecting data of greater quality, and the survey of challenging archaeological sites that still are difficult to tackle with traditional means. Some important developments that lend themselves to the advancement of our discipline are outlined below.

## Increasing data quantity

Closer channel spacing and wider sensor arrays and the use of affordable precise positioning systems – RTK-GNSS receivers in base-rover or network/NTRIP configuration –

offer increased data quantity in equal time spend. Partly, higher data sampling speed permits increased survey velocities and thus larger coverage rates. This is valid not only concerning motorised prospection systems, but similarly regarding for instance manually pushed single-wheel four-channel magnetometer carts equipped with an RTK-GNSS rover antenna for efficient mapping of ancient building terraces in challenging terrain. Multichannel EMI arrays as developed by the experts from Ghent University will lead to an increase in data quantity (Hanssens et al. 2021). The advent of semi-autonomous all-terrain or agricultural vehicles will permit continuous, driverless data acquisition following well defined survey patterns (Nau et al. 2023). While magnetometer sensors deployed from drones for UXO detection may be of interest for archaeological prospection, endurance and flight altitude is still a major issue when it comes to the coverage of large areas. While increasing sampling density and the size of the survey areas are important, data quality should always have highest priority.

## Enhancing data quality

New hyper-stacking, real-time and high-dynamic-range GPR antennae and miniaturised optically pumped magnetometers permit prospection data with greater penetrating depth, respectively sensors with increased sensitivity. Step-frequency single channel and array GPR promise wider frequency bandwidths and thus optimized depth-imaging. Precise data positioning is of paramount importance for great data quality. The availability of precise RTK-GNSS receivers at considerably reduced cost, having seen a drop in price of a factor of 10-20 in recent years, offers the possibility to mount more than one satellite receiver on the same survey system (dual-head RTK-GNSS solutions), which in case of sensor arrays offers greater control over system orientation, heading and tilt. Through utilisation of inbuilt inertial measurement units (IMU), the movement of the geophysical system can be recorded more realistically, opening up for new data processing approaches for more precise imaging. For instance, this could be used to detect and remove variable unwanted systematic noise (e.g. caused by swinging of sensor carts) from the data, through locally adaptive frequency filtering (Schmidt et al. 2020).

## 3D surface and subsurface imaging

Laser scanning and photogrammetric image based modelling allows for the efficient 3D recording of the surface of investigation areas. The combined 3D surface and subsurface imaging approach can be handled separately or simultaneously, by either 3D scanning/imaging the surface prior to or after the geophysical prospection survey (Merkle et al. 2021), or alternatively through integration of affordable mobile LiDAR sensors and cameras on the geophysical survey systems. The combined visualisation of surface and subsurface data permits not only the generation of a more realistic virtual scene of the encountered situation – and thus the possibility to detect causes for disturbances in the data – but offers the viewer immediate recognizable scales for enhanced understanding of the size of anomalies and structures in the data. Recording the micro-topography of the survey area will allow for more precise data positioning and enhanced data imaging. Combining multibeam sonar bathymetry data with subsurface sediment sonar data for enhanced 3D imaging of underwater archaeological sites is to be seen equivalent.

## Prospecting challenging environments

While large, open, unobstructed areas already can be prospected efficiently, sites located in obstructed environments such as forests, plantations or high-rise built-up areas can be very challenging to explore due to insufficient availability of efficient data positioning solutions. The concept of visual simultaneous localization and mapping (visual SLAM) and LiDAR based odometry and mapping (LOAM) is a highly promising development (Shan et al. 2020), utilising small LiDAR sensors or stereo-cameras to provide local relative position information by recording the movement of the system through the obstructed, RTK-GNSS-denied environment (woods, urban areas, indoor, caves). By linking the geophysical prospection data with the position information through precise PPS time stamps, a link for merging position and prospection data during processing can be made. When continuously mapping spatially extent areas, challenges are loop-closure detections and SLAM/LOAM data management to achieve sufficient operation durability due to the large amount of laser scanning or feature point data recorded for position determination. The integration of IMUs as well as of RTK-GNSS sensors for the recording of supporting points with global position infor-


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mation enhances the approach, wherever available. By copying the successful large-scale high-resolution terrestrial geoarchaeological prospection approach to shallow underwater environments, similar successes regarding discovery and exploration of underwater archaeological cultural heritage, alongside natural wonders, will be possible. Tidal flats, streams and bogs are as challenging as promising environments.

## Extracting more information from prospection data

The development of new data formats, fully describing the acquired prospection data, comprising all available information, such as measured amplitude, system speed, sensor orientation and distance to the ground, voltage, quality of position data, distance to nearest neighbour, permit the generation of maps illustrating data quality and variations therein, as well as the development of new data processing algorithms. Such maps will be fundamental for the identification of and differentiation between systematic noise/errors and subsurface anomalies, rendering data interpretation more reliable. Automatic and semi-automatic data segmentation facilitate the generation of interpretation maps (Trinks et al. 2020). The adaptation of the successful, efficient feature extraction from magnetic prospection data to full 3D GPR data segmentation remains on the to-do list. While GPR amplitude maps are useful for the identification of anomalous regions in the data, we need to be able to quickly, interactively query large data sets to extract freely spaced full-trace profile sections and individual GPR traces for enhanced understanding of the data. Adapting and applying algorithms developed by the geophysical prospection industry, such as seismic attribute processing for innovative GPR data analysis (Trinks and Hinterleitner 2020), or potential field continuation and routine reduction-to-the-pole magnetic map generation, has the potential to substantially enhance data imaging and thus data interpretation possibilities. The possibilities offered by GPR (Warren et al. 2016) and magnetic data simulations remain unutilized and could substantially help to improve the understanding of prospection data, and to investigate the physical boundaries of detectability and imaging potential for specific scenarios. The quest for joint data inversions, e.g. by linking magnetic and GPR data through EMI data, remains the holy grail.

## Advancing the understanding of prospection data

Through immediate routine geoarchaeological minimum-invasive coring/sampling of the soil at selected anomalies and areas of interest, using augers and direct-push sensors (Völlmer et al. 2018), it will become possible to gain an improved understanding of the causative structures in the ground, without destroying them through excavation. The measurement of physical soil parameters is necessary to understand the cause of observed anomalies. The nature of our discipline is inherently highly interdisciplinary. A major challenge will be to get funding bodies to accept that the evaluation of related research and development proposals has to reflect that fact. The potential to generate better prospection results is great. Exciting archaeological discoveries are waiting to be made and endangered cultural heritage is in need of documentation. Let's do it!

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