Spatial processing of multiple source prospection data in landscape archaeology

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ABSTRACT
In a project dealing with landscape archaeology the Institute for Pre- and Protohistory of the Mainz University and the Institute for Spatial Information and Surveying Technology (i3mainz) have been examining the area of the Celtic oppidum “Hunnenring” in the northern Saarland (Germany) since the end of 2006. The monumental northern wall of this prehistoric town is preserved up to a height of 10 m, which makes it the most massive fortification-structure in the whole Celtic world. Various sources indicate that the low mountain range, which is nowadays situated peripherally, used to be a significant centre with supra-regional importance in Celtic times. By using various archaeological prospection methods and the methods of applied geoinformatics and surveying technology it is attempted to reconstruct the pre- and protohistoric habitat as detailed as possible. Special emphasis is placed on tracking early use of resources and on the question to what extent local iron ore and copper deposits affected the economic activities of people. High-resolution Digital Terrain Models (DTM), which were generated by using Airborne Laser Scanning (ALS) data and Terrestrial Laser Scanning (TLS) data, are a core component and the starting point for targeted prospections in this respect. The information, that was generated by using various methods such as geophysical prospection, surveying of single finds, ALS and diggings, is stored related to each other in a Geographic Information System (GIS) and is, combined with significant factors such as soil quality, geology, waterlogging, slope and water proximity, well to be included in analysis of settlement history.

1. INTRODUCTION
The description of the pre- and protohistoric habitat with its network of human settlements, its cultivation and field areas and its natural resources is referred to as landscape archaeology. In many cases archaeological research relies on excavations and analysis of findings as scientific methods. Landscape archaeological research, working at the landscape scale, can not meet these requirements, because the excavation of a whole landscape is impossible. Hence research here relies on special prospection techniques like surveying of single finds, geophysical prospection and aerial archaeology, which all aim at retrieving historical sites without disrupting their archaeological context.

In recent times landscape archaeological research increasingly uses methods and technologies of photogrammetry and geoinformatics for approximation of the prehistoric habitat. In particular the use of Airborne Laser Scanning (ALS) is applied in archaeology to produce detailed relief maps of archaeological sites. But ALS also has a high potential for detection of unknown archaeological sites and structures. In woodlands the accuracy of the ALS-Data sometimes is insufficient. However, at least smaller wooded areas containing archaeologically interesting structures can be detected by use of Terrestrial Laser scanning (TLS).

A Geographic Information System (GIS) provides for good capabilities to visualise and to combine the information, as gained by different methods. As an analytical tool the GIS helps to identify indications for further prospection activities.

2. PROBLEM DEFINITION
The Celtic oppidum “Hunnenring” with its fortified walls preserved up to a height of 10 m and a total length of over 2 km (Fig. 1a) is situated on the ridge of the Dollberg Mountain (Fig. 1b) in northern Saarland (Germany). The large amount of human resources needed for construction of these fortifications indicates that this Celtic town from the 2nd and 1st century BC used to be a significant centre of supraregional importance and also a home to the local elite. Further on, evidence like the existence of princely tombs furnished with imported bronze vessels and golden jewellery as well as settlement finds from the Hunnenring itself, both dating to about 400 BC, seem to indicate that the later oppidum is merely following structures of centralization established two centuries earlier.
Whereas for the second and first century BC the Dollberg plateau which comprises 18.5 ha obviously served as a central settlement for a major community and thus as economic, political and possibly religious centre, other finds from the immediate vicinity indicate that settlement activities continued throughout the following Roman period as well. From an archaeological point of view the question which economic factors led to the rise of this region in Celtic times is of particular importance and can be judged only in conjunction with research on the conditions in Roman times. Its waterlogged and nutrient-poor soils may hardly have served for other than subsistence agriculture. And even though local deposits of copper and iron-ore seem to be of comparably low quality, they may have been the economic basis for the development of social organisation-structures and settlement-hierarchies in Celtic and Roman times. Hence the intention of landscape archaeological research in this area is to find proof of prehistoric digging activities for iron ore and copper and thereby collect evidence to support a theory that in the past has been discussed mainly on a theoretical level. To achieve this aim, selective prospection of archaeological sites in the region is conducted.

In 2007 prospection work concentrated on an area of appr. 20 ha, which is situated 1.2 km southeast of the Hunnenring close to the village Otzenhausen (Fig. 2). In this area a Gallo-Roman temple with a surrounding civil settlement was excavated in the 1980s. The territory lies within the local subdistrict "Auf dem Spaetzrech" and consists nowadays of several areas of grain cultivation, meadows and some unused parcels of land. The area is surrounded by protected spruce plantation areas and mixed forest. In the Muenzbach valley, which is situated to the northeast and which represents a distinctive score in the terrain, also mixed forest is rising. The aim of the prospection was to gain further knowledge about the expansion of the settlement and to find indications of pre- and protohistoric metal smelting.

3. METHODS OF PROSPECTION
A combination of different archaeological prospection techniques and methods of surveying technology was used to achieve this aim. The results were used for visualisation in a GIS and applied for further analysis. In the following sections the used methods of prospection will be described and discussed.
3.1 Topographical survey
The recording of anthropogenic characteristics of the relief is a common method of archaeological prospection. For this purpose the terrain is surveyed with a total station as a regular grid and this grid is densified in regions with overly anthropogenic changes of the earth’s surface. The recorded terrain points are used for creation and visualization of a Triangular Irregular Network (TIN) in a GIS. By this means very fine characteristics of the relief, like terraces of settlement, old routings and historical mine shafts can be documented very well.
In the recent past ALS-Data are used increasingly for archaeological applications because of their potential to determine a dense point cloud (up to several points per m²) in high quality. These data are an efficient alternative to the classical topographical survey by using tacheometers, particularly in wooded areas where good conservation of archaeological structures is indicated. For smaller regions a terrestrial laser scanner provides for an excellent alternative to generate a high resolution DTM.

3.2 Recording of single findings
A conventional archaeological prospection technique is the collection of single finds. For this purpose a ploughed acre is paced off systematically and the positions of finds are recorded by using total station or GPS. However in woodlands only selective not constant seeking of objects is possible. In this case soil exposures of every kind are used: waysides, lanes of forest vehicles, river beds, root plates or other places without vegetation. Typical and common soil exposures of meadows are molehills. In order to interpret the disposition of archaeological finds in molehills the position of every single molehill has to be recorded. This is the only way to differentiate between areas with finds and areas without.

3.3 Geomagnetic prospection
Particularly for detection of metalliferous materials the use of geomagnetic prospection is a very helpful method. Geomagnetic prospection is a method, which utilizes the property of the terrestrial magnetic field to induct every kind of material magnetism. The level of induction can differ for geomagnetic sensitive materials like stone, metalliferous objects or pottery considerably. Due to induction of the terrestrial magnetic field every body becomes itself a specific magnet with its surrounding magnetic field. This magnetic field superposes with the inducted (so called normal) earth magnetic field as interfering field. In this way the specific field produces anomalies in the normal earth magnetic field. Recording and analysis of such anomalies yields a method to detect ditches, pits and other filled-in intrusions of the ground, but also high temperature areas e.g. in sections of smelting.
The surveying of the anomalies is executed by means of special instruments (Caesium-Magnetometer or Fluxgate-Gradiometer) and permits the finding, delimiting and modelling of magnetic objects. The measurement in the field is done by capturing the anomalies along a regular pattern in the field. During measurement the measuring values are recorded in a dense interval in a decimetre range. Data management takes place by using special software programs for processing of geomagnetic measurements or in stand alone image processing software. The measuring values of anomaly measurement are represented as gray scale values, the scale of which is specified by requirement and estimation of a geophysicist.

4. EXECUTION AND RESULTS
At first the study area was explored by inspection of the terrain with regard to topographically interesting areas. Especially the relief of the Muenzbach valley shows a multiplicity of significant anthropogenic changes. In this area a recent stone pit is sticking out. Moreover, a food path and some distinctive patterns of boulders on the earth surface are forming the characteristic features of this area. All this leads to the hypothesis of an ancient pathway connecting the Hunnenring to a nearby Roman settlement. In order to achieve a most homogeneous representation of the terrain with regard to detail DTM’s were generated by means of total station data, ALS data and TLS data. This strategy made it possible to compare the results which were obtained by different methods.
The surveying of the terrain by total station was accomplished with a number of 17000 points, whereby especially in the valley of the Muenzbach the point density raised up to 4 points/m². In the GIS ESRI ArcGIS a TIN was generated from the measured points (Fig. 3).
Also in ArcGIS a TIN was generated from ALS data with an average point density of 1.5 points/m². The resulting TIN’s show a clearly recognisable structure to the south of the Roman temple, which has the shape of a rampart (Fig. 4). During excavation in the 1980s this rampart was interpreted as being the border of the Roman settlement.
The area of the recent stone pit was surveyed by means of TLS. A 1 ha size area consisting of the recent stone pit and its surroundings was recorded with the Leica Laser Scanner HDS 3000 from 9 positions with a terrain point accuracy of 5 cm. The single scans were registered and merged together in the program Leica Cyclone. With a program for elimination of useless laser points (points which lie above the earth surface), which was developed by the i3mainz, the scan was filtered in a way, that the subsequent error handling was minimized. The program converts the point cloud to a defined raster and extracts for every raster cell the lowest point. The resulting point raster undergoes another thin out procedure by use of different neighbourhood operators. After passing this automatic program routines the remaining non surface points were disposed interactively in the program Raindrop Geomagic and accordingly processed as TIN in ArcGIS with an average height accuracy of 15 cm (Fig. 5).

As expected the Terrestrial Laser Scanner identifies the relief of the recent stone pit in the most differentiated way. A line structure, which slopes down into the river valley of the Muenzbach and which continues on the other side of the shore, was of particular interest to the archaeologists. This structure possibly could be associated with the already mentioned patterns of boulders, suggesting a direct connection to the Hunnenring.

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**Fig. 3:** Shaded DTM as a result from topographical recording of the working area and showing the rampart and the recent stone pit.

**Fig. 4:** Shaded DTM of the working area as a result from Airborne Laser Scanning.

**Fig. 5:** Visualisation of the recent stone pit in ArcScene.
Inspections were accomplished and single finds were recorded in the centrally located agricultural cropland of the working area and in the forested area northwest of the temple. In the wasteland area and at the meadow grounds about 273 molehills were prospected and investigated for finds. Approximately 1400 single finds were categorized and visualized in ArcGIS (Fig. 6). It turns out, that the major part of the finds consists of brick fragments, which concentrate clearly on an area south of the temple. Thus this area can be interpreted as the centre of the former settlement. Towards the south finds are thinning out with increasing distance. A major number of bricks was found in the forest northwest of the temple and in the Muenzbach valley. It is indicated that the allocation of the finds extend to a larger area as suspected before which leads to the conclusion that the settlement had a greater expansion than had been assumed so far.

The adjacent area to the south of the temple was prospected by a geomagnetic survey, the results of which were visualised in the program Golden Software Surfer. Clearly recognizable linear structures can probably be assigned to the settlement, while two striking anomalies southwest of the temple can be linked with iron processing or smelting (Fig. 7). Besides finds like Roman pottery sherds, finely distributed slag pieces were found in the whole prospected area. As there were also recent pottery and glass finds on the acres, those collected slags could possibly be of recent age as well. This hypothesis could be refuted by the results of an excavation at the position of an anomaly, which was identified on the geomagnetic image and which correlated with a peculiar high concentration of slags (Fig. 8). As a result of the excavation the anomaly was found to be caused by a roughly 40 cm strong, thick dark grey up to black layer beyond the plough horizon. The major material within the layer consisted of slags, Roman bricks and fragments of pottery. Beneath the plough horizon there were exclusively Roman finds, the same can be said about the excavated material.
5. CONCLUSIONS AND FUTURE WORK
By use of different methods and techniques of archaeology and surveying knowledge about the Roman settlement “Auf dem Spaetzrech” could be improved significantly. Different methods of topographical surface recording were used to produce detailed topographical maps of the study area. The resulting Digital Terrain Model DTM proved to be of great help to sharpen the image of the historical landscape. The results of geomagnetic prospection and of the collection of single finds were visualized in a GIS. It could be shown, that those single finds are distributed over a wider area than suspected so far, which means that the Roman settlement had covered a larger area than was assumed previously. The geomagnetic image was combined in the GIS with the distribution of slags and proved a correlation between geomagnetic anomalies and a high concentration of slags. The excavation at the position of this anomaly provided evidence of antique iron processing. An area of about 1 ha size in the Muenzbach valley was scanned with a terrestrial laser scanner to get a much more detailed image of the topography than was obtained from the results of Airborne Laser Scanning ALS and topographical recording. The point cloud of the scan was processed by a special software, which was developed at the i3mainz. This software provides an efficient tool to remove effectively most of the points which are useless for topographical representation. The resulting DTM showed a small structure, which possibly belongs to a pathway connecting the Roman settlement with the Hunnenring. The efficient processing of the TLS-data also showed that the use of a Terrestrial Laser Scanning TLS in wooded areas is a good alternative to ALS and conventional topographical recording.

Further research will concentrate primarily on the proof of mining tracks. In this context an important starting point will be the processing and visualisation of ALS data. The intention is to process such data in a way, which is well adapted to the extraction of archaeological structures. In the GIS important location criteria like the spatial pattern of soil quality, geology, waterlogging, slope and water proximity will be managed and will be set in reference to the archaeological finds, in order to predict potential locations for further archaeological sites.

6. REFERENCES