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Aerial photograph and digital terrain model derived  
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## AERIAL ARCHAEOLOGY AND AIRBORNE LASER-SCANNING AT THE IRON AGE HILLFORT SCHWARZENBACH-BURG

*Michael Doneus, Wolfgang Neubauer*

*Recent technical developments suitable for archaeological prospection have been successfully applied in Schwarzenbach-Burg. Apart from the geophysical survey aerial photography was used so far to monitor the archaeological site and its surroundings and to measure its topography. The prospecting archaeologist from VIAS cooperating with the aerial archaeologist from the Department for Prehistoric and Mediaeval Archaeology of the University of Vienna have been using airborne laser-scanning to look through the forest partly covering the late Iron Age hillfort and its surrounding. The resulting detailed digital terrain model provides a detailed insight into the archaeological structures still surviving in the topography. The cooperation demonstrates that only an integration of different prospection methods will enable effective heritage management and archaeological research.*



*Fig. 1: The Iron Age hillfort of Schwarzenbach during the first Celtovation-festival in June 1998. The area of the ongoing archaeological excavation is in the foreground. The village of Schwarzenbach is in the background (view from east).*



*Fig. 2: The same situation as in Fig. 1, as seen in March 2006. An exhibition tower now dominates the center of the hillfort. In front of the tower are reconstructions of the archeological park. Although the deciduous trees are still without leaves, the ramparts are invisible in the aerial photograph.*

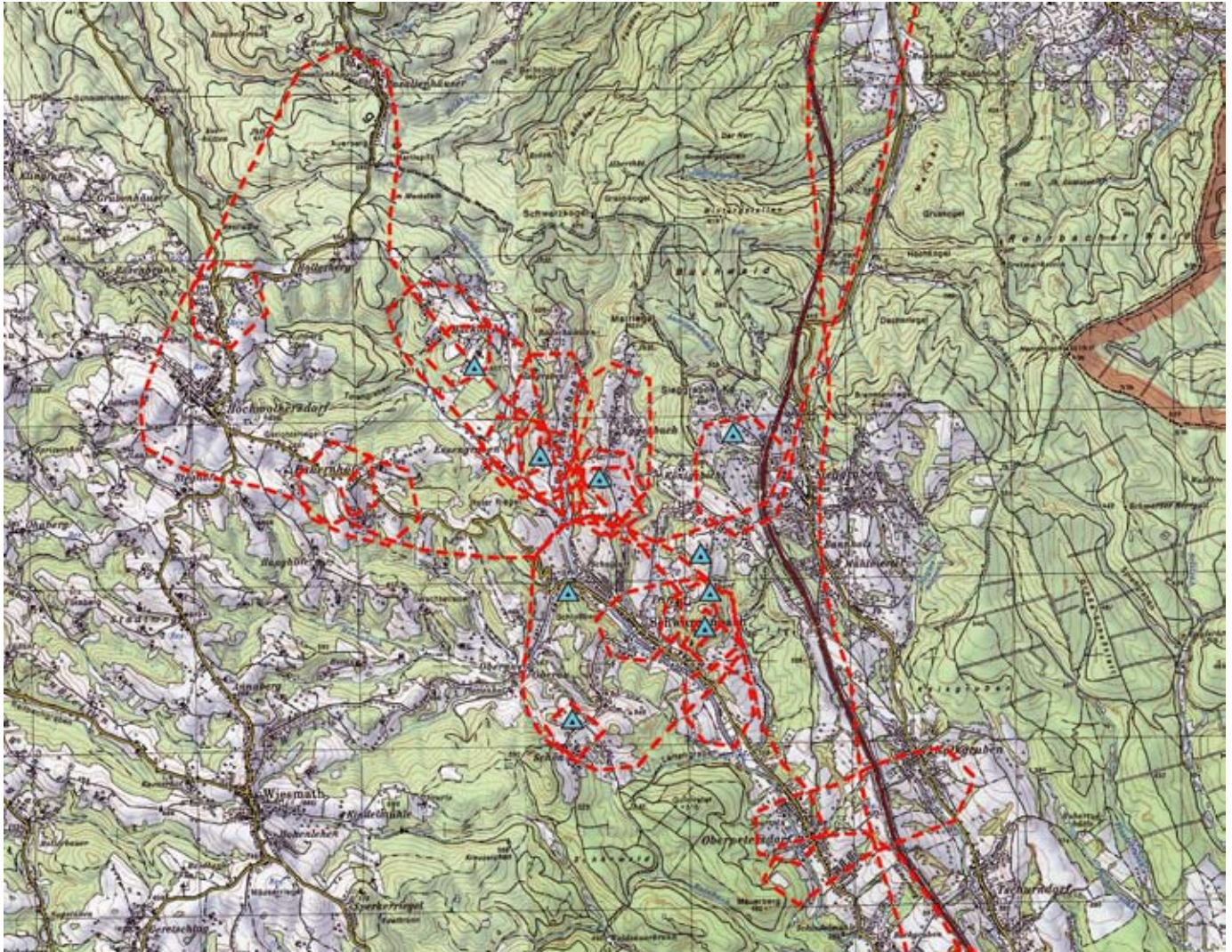


Fig. 3: Flight path of a reconnaissance flight during June 2003. The track was recorded using a GPS receiver.

### Conventional Aerial Archaeology for monitoring and reconnaissance

Currently, archaeology is using mainly three prospection methods for the systematic (i.e. not coincidental) reconnaissance of archaeological sites: field survey, aerial archaeology and geophysical prospection. Aerial archaeology is a very cost-effective method for site discovery, but often does not provide details about individual structures of a site as for example posts or palisades or dating evidence. A detailed plan of the discovered sites can be provided by geophysical prospecting techniques, while field walking can provide the archaeologist with information on the physical conditions on the ground and with primary dating evidence for a site. Aerial archaeology is a very productive aid for archaeological survey as many archaeological sites show up on the ground surface, depending on their state of preservation by light-shadow-contrasts (shadow-marks), tonal

differences in the soil (soil-marks), or differences in height and color of vegetation (crop-marks). Settlements, graveyards, fortifications etc. produce specific structures that can be identified easier from a high viewpoint. Especially crop-marks sometimes produce detailed and clear projections of the buried structures. Schwarzenbach-Burg and its surrounding area is covered on more than 250 aerial photographs stored at the department's aerial archive. Both vertical and oblique aerial photographs are used for interpretation. The oldest ones are from April 1965, but the majority dates from the years since 1992, when the co-operation with VIAS had started (Fig. 1, 2). The area of the hillfort Schwarzenbach-Burg is partly covered by woods. The non-forested areas consist of farmed grassland. Therefore, it was clear from the beginning that aerial archaeology would not give many insights into the buried archaeological features of the site.



*Fig. 4: Situation of the archaeological excavation in July 2003.*



*Fig. 5: The same area as in Fig. 3, as photographed in June 2007. After the excavation was finished, the area was used for building an ensemble of Iron Age houses.*

The strategy was therefore to prospect the non-forested parts of the site using geophysical methods. Aerial archaeology was used to document the site in its landscape and to monitor the hillfort with the ongoing archaeological excavations and its surrounding area (Fig. 4, 5). Vertical aerial photographs, produced by the Austrian Air Force at Langenlebern, are available for the aerial archaeology unit due to a contract between the Ministry of Science and the Ministry of Defence. They are taken using a photogrammetric large-format camera (Zeiss RMK), both on B&W and infrared false-color material. While taking the photographs looking straight downwards, the airplane flies over a certain area in a meandric way, so that the whole area is covered by overlapping photographs. The overlapping parts can be seen stereoscopically. They are most suitable for photogrammetric analysis and can be analyzed in three dimensions (Doneus, 1996). 15 years ago the topographical information of the main fortified area of Schwarzenbach-Burg was measured from vertical stereopairs for subsequent archaeological investigations, prospection as well as excavations.

Another important data source are oblique photographs. These are made by a trained archaeologist using high-wing airplanes, usually a Cessna 172. While flying, the aerial archaeologist is able to choose the parameters of the flight and has the possibility to investigate the marks showing on the surface and decide upon their archaeological relevance.



*Fig. 6: Potential features of a former settlement north of Schwarzenbach.*

Navigation and flight recording is done using a GPS receiver. The flight path is continuously recorded and the approximate position of each photographed site is stored using waypoints for later use in a GIS environment (Fig. 3). Flightpaths give also valuable information about areas with “negative” response, i.e. areas where no archaeological traces could be found on that specific flight. For oblique aerial photography, digital cameras with a resolution of at least 12 megapixels are used. This results in high quality documents, which are the basis for subsequent interpretation. During reconnaissance flights in 2003, some areas in the vicinity of the Iron Age hillfort could be photographed, which show potential traces of antique settlements. Figure 6 shows an already ripened field of wheat or barley. Some more or less parallel linear structures are running through the field, which show as light marks and are of geological origin. Among these linear features, a few round and square crop-marks become evident, which could be pits and the remains of sunken floor houses of a former settlement.

### **Airborne Laser-scanning – a new technique for archaeological prospecting**

Aerial archaeology and geophysical prospecting come to their limits in wooded areas, which results in the fact that we usually know only large and well-preserved sites in forests. Systematic detection of archaeological sites in woodland has therefore until recently been one of the unsolved problems in archaeological prospecting resulting - not only in Austria – in a big deficit of archaeological knowledge from forested areas. Over the past few years, airborne laser-scanning (ALS) also known as LIDAR (Light Direction and Ranging), has turned out to be a potential tool for recognising and measuring topographic earthwork features in wooded areas ( Wehr and Lohr 1999, Doneus and Briese 2006 including further references), but can only render a limited range of types of archaeology, the ones still surviving in (micro-) relief.

From the aerial photos, it becomes clear that archaeological features within the wooded parts of the hillfort Schwarzenbach-Burg would not be visible from the air. The contour map of the site, measured from vertical stereopairs, provided the topographical information of the hillfort for further archaeological investigations, but was only a basic topographical map. For a detailed interpretation of the archaeological features, the topographical information would need a much higher resolution than could be achieved using conventional photogrammetric techniques. These needs can be addressed using ALS.



*Fig. 7: Digital Surface Model of the site showing the extent of the vegetation cover.*



*Fig. 8: Digital Terrain Model after removing all but the last echoes of the data set and filtering using the technique of robust interpolation.*



*Fig. 9: 3D-view of the airborne laser-scanning scene. The hillfort is seen from southeast.*

Its applications in archaeology are successful although still rare, but it turned out to be a possible tool that can help to solve problems with the recognition and measurement of preserved sites especially in forested areas. The laser scanner is usually mounted below a fixed wing aeroplane or helicopter, where it emits short infrared pulses towards the earth's surface into different directions across the flight path (typically 30,000 to 100,000 pulses per second). Each pulse will result in one or more echoes reflected from various targets as vegetation, buildings, cars, ground surface along its path. While in theory a good deal of first echoes return from the top of trees and buildings (off-terrain points), the last one should be returning from the ground surface (terrain points). The location of each reflecting object is calculated using the angle of the emitted laser beam, the distances to the reflecting object (measured by the time delay between emission and each received echo), and the position of the scanner typically determined using differential global positioning system (dGPS) and an inertial measurement unit (IMU). Because of the high density of measured points and their more or less even spread, the digital terrain models are very precise. The

absolute accuracy usually lies within a range of +/- 20 cm in plain and +/- 15 cm in height. The vertical relative accuracy, i.e. the minimal vertical extension of objects to be measured lies between 5 and 10 cm. By selecting only the first echo of the scanned data, a digital surface model (DSM) can be derived (Fig. 7). Using only the last echo point cloud (last echo data) will theoretically result in a digital terrain model (DTM) representing the surface beneath the vegetation cover.

For archaeological interpretation, a high quality DTM has to be derived from the ALS data. This involves a reliable separation of terrain and off-terrain points while maintaining a high point density.

Currently, there are two different types of ALS sensor systems available: discrete echo scanners (conventional scanners) and full-waveform scanners. Discrete echo scanners detect a limited number of echoes for each laser pulse in real time using analogue detectors. While most detectors deliver only the first and last echo, some can distinguish up to four distinct echoes from multiple targets from a single laser pulse. These sensors can be considered to be "lossy" as the majority of the

received signal is discarded by the analogue detectors. Full-waveform scanners sample the entire analogue echo waveform for each emitted laser beam, typically with an interval of 1 ns. Therefore, they discard significantly less data than conventional scanners during the data collection process.

The echo waveform will be post-processed, where the individual echoes are extracted using algorithms that can be adapted to the physical and biological environments within which the laser interacts (Wagner et al. 2006, Hug et al. 2004). Tests showed that full waveform systems usually yield better results with low and dense vegetation, which affects the reliability of the derived DTMs (Doneus and Briese 2006).

In Schwarzenbach, a RIEGL Airborne Laser Scanner LMS-Q560 ([www.riegl.com](http://www.riegl.com)) operated by the company Milan Flug GmbH ([www.milan-flug.de](http://www.milan-flug.de)) was used to collect the full-waveform ALS data during April 2007. To derive a DTM from the data, initially, all echoes except the last ones are discarded as these will always be off-terrain. The next stage is to discriminate between points which represent actual terrain reflection and those which are derived from other off-terrain features (tree trunks and notably dense vegetation). These effects can be reduced by employing advanced filter methods (Sithole and Vosselman 2003). Both georeferencing and filtering of the full-waveform data was done in cooperation with the Institute of Photogrammetry and Remote Sensing of the Technical University of Vienna (Doneus et al. 2008).

In this way, most of the forest canopy and brushwood covering the archaeological features could be removed. The resulting DTM of Schwarzenbach-Burg shows a detailed map of the topography with even faint archaeological structures under the forest canopy and therefore clearly demonstrates the high archaeological value of full-waveform airborne laser scanning (Fig. 8). The outline of the hillfort can be clearly seen through the forest canopy, with varying structure of trees and bushes. The naturally undefended part of the hillfort is protected by a rampart, which has completely survived on the northern, western, and partly on the southern side. In the north and partly in the east, it is accompanied by a ditch. The rampart encloses a seemingly square area, with a size of roughly 250 by 250 meter, which first became obvious by this new data. It was not visible before that the rampart shows such rectangular corners. On the eastern and southern side, the hillfort extends outwards and is constrained by steep slopes (Fig. 9).

As geophysical prospection did prove the former rampart was destroyed by agricultural activities. Two thirds of the central area is cut off by an inner rampart, which could be from an earlier phase. In the northeast corner of the site, the DTM shows a variety of depressions, which are partly extraction pits and partly remains of medieval kilns.

## Conclusion

Using airborne laserscanning, the terrain under the forested parts of the Iron Age hillfort can be modeled giving a detailed view of the archaeology surviving in the topography. The results of each survey technique provide valuable information, but each has its own biases and limitations. It is only by combining the techniques in an integrated programme that it is possible to gain a more complete overview of a region's buried archaeology and so allow the effective management of its heritage.

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This research has been supported by the Austrian Science Fund (FWF) under project no. P18674-G02. Both analysis and georeferencing of the full-wave data is done in cooperation with the Institute of Photogrammetry and Remote Sensing of the Technical University of Vienna. For the filtering of the data we use the software package SCOP++ where robust interpolation with an eccentric and unsymmetrical weight function is applied. A brief description of the technique is given from Doneus and Briese (2006). The whole process of filtering is also demonstrated at the EuroSDR Distance Learning Course "Filtering and Classification of Laser Scanner Data", available at: <http://www.ipf.tuwien.ac.at/eurohdr/index.htm>.

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### Zusammenfassung

Die befestigte Höhensiedlung von Schwarzenbach-Burg ist bereits seit 15 Jahren Fokus einer Kooperation zwischen VIAS und der Abteilung für Luftbildarchäologie am Institut für Ur- und Frühgeschichte der Universität Wien. In diesem Zeitraum wurde die Höhensiedlung wiederholt aus der Luft fotografiert.

Hauptzweck der Befliegungen war die Darstellung der Fundstelle im Kontext mit ihrer Landschaft sowie die Dokumentation der fortlaufenden Ausgrabungsarbeiten. Dadurch besitzen wir heute eine Zeitreihe, welche auch die Veränderungen der Landschaft während der letzten 15 Jahre sichtbar macht.

Um die ansonsten nur unter schwierigen Bedingungen prospektierbaren archäologischen Überreste der vom Wald bedeckten Flächen zu visualisieren, konnte mit „full-waveform airborne laserscanning“ die momentan aktuellste zur Verfügung stehende Technologie eingesetzt werden. Mit Hilfe des flugzeuggetragenen Laserscanners lassen sich präzise und detaillierte Geländemodelle selbst unter dichter Vegetation erstellen. Anhand dieser Daten können heute sogar nur noch extrem flach im Gelände erhaltene (+/- 5-10 cm Höhenunterschied) archäologische Überreste erkannt werden. In Schwarzenbach konnte somit zum ersten Mal eine detaillierte Gesamtansicht der Höhensiedlung erstellt werden, die Wälle, Gräben, Plattformen und sonstige ehemalige anthropogene Eingriffe im Boden zeigt.



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