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Collection, visualization and simulation of magnetic prospection data

1 Introduction

The majority of our archaeological heritage is buried in the ground and archaeologists are interested in the exploration of the landscape for remains of past human activity. For non-intrusive location of archaeological structures magnetic prospection is an appropriate technique. It is a fascinating discipline under continuous development and has become an important tool of research in Austrian archaeology (Melichar 1990; Melichar/Neubauer 1993; Neubauer 1990). Especially in Lower Austria, we know many archaeological sites easily prospectable by magnetometery. They are mainly situated in homogeneous loess with low susceptibilities ($\kappa \approx 10 - 20 . 10^{-5}$). Sites are commonly close to the surface and are known due to the last twenty years of systematic aerial photography (Doneus 1994; Fenster zur Urzeit 1982). The archaeological features in the landscape generally have geometric properties different from those of the natural surrounding. Most monuments discovered by aerial photography are being steadily and rapidly destroyed by erosion. Those sites cover areas of many hectares. For precise measurements of large areas in a short time we had to develop both apparatus and techniques. High speed, highest achievable accuracy and spatial resolution are required for an efficient collection of magnetic data. Optically pumped magnetometers have proved to be the appropriate instruments for archaeological prospecting. During the last seven years a cesiumgradiometer with automatic position control and data acquisition has been developed and improved continuously. Site surveys have been carried out systematically on various sites all over Austria.

2 Measuring Device and Data Collection

In a cooperation between the Austrian Central Institute for Meteorology and Geodynamics and the Institute for Prehistory we developed an automatically recording cesiumgradiometer device. The magnetic scanning system ARCHEO PROSPECTIONS® used in Austria is mounted on two completely unmagnetic wooden wheelbarrows. The main wheelbarrow carries the two alkali vapour sensors. The two cesiumsensors are fixed in a plexiglas tube for gradiometer array, measuring the difference of the total magnetic field. In this tube the sensors can be positioned at several heights resulting in different gradients. The first sensor at 50 cm and the second at 2 m above groundlevel is the commonly used gradiometer array. To ensure a vertical gradient the tube is able to swing like a pendulum. For this movement in all directions we constructed a kardan. The gradiometer system operates with a specified accuracy of 0.05 nT. With the optically pumped cesiummagnetometer, being an oscillator at a relatively high frequency, 11 readings can be taken per second. To reach a maximum measurement speed in the field, the gradiometer system is connected to an automatic positioning and data recording system. Thus the survey can be carried out continuously without limitations of the apparatus. The data logger and the gradiometer readout unit are mounted on a second wooden wheelbarrow which is connected to the first one by a 50 m long cable. The automatic position control is realized by optical detection of the wheels rotation. The measuring process is controlled by two audio signals.

For the survey the area of interest is divided into rectangles by using a theodolite and fixed by absolute coordinates. The rectangles themselves are normally measured with 50 or 25 cm grid spacing driving in zigzag. Because the terrain is not always smooth, the count of position impulses from the rotating wheel is varying.
To reduce these errors a test line is measured for every rectangle and the count of position impulses is used for calibration. The system is operated by three persons. Under normal conditions about 8 000 square meters can be easily prospected in one day, that means a recording of up to 64 000 readings per day with a spatial resolution of 0.5 × 0.25 m. Sofar the system has recorded about four million readings.

3 Visualization and data processing

In the field the magnetic data are stored in binary format on a laptop computer. Every measured rectangle is represented by one binary data file and an information file for optional corrections. All data files are arranged by their coordinates to compose the resulting image by using a special grid description file. For visualization of the data various data formats are produced by the developed image composer.

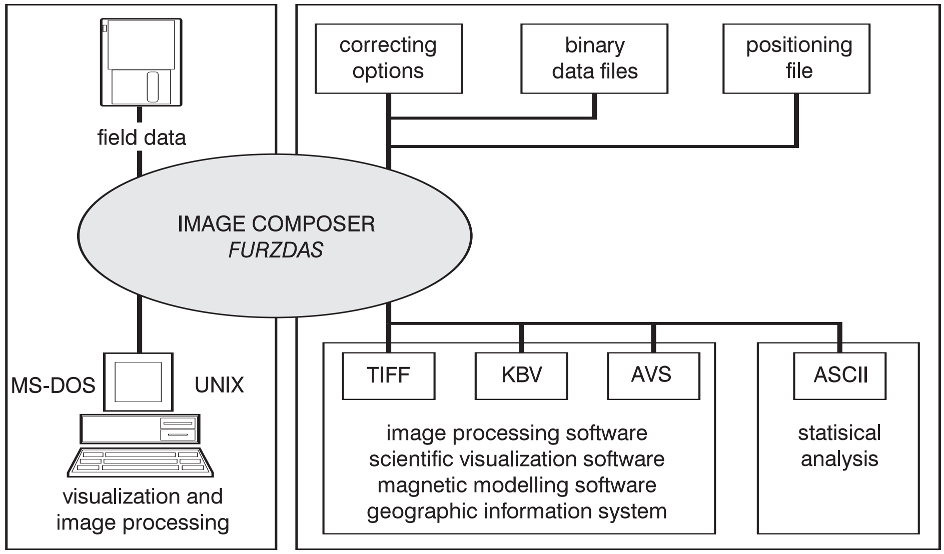

Figure 1. Visualization as a digital image.

TIFF-files can be imported by almost all available digital image processing software for MS-DOS or Windows. Other formats are necessary for input to image processing and scientific visualization software under UNIX on work-stations (see fig. 1).

Every single reading in the field is represented by one pixel on a high-resolution screen. The range of the greyscale is 0 to 254 using 8 bits for representation of one value. For visualization of the mostly very weak archaeological anomalies every 0.1 nT has to be represented by one grey tone. In that way only a range of -12.7 to 12.7 nT can be displayed. Zero nT is therefore given the medium grey tone 127, values bigger than -12.7 nT become white, values smaller than 12.7 nT get black. This is enough because almost all the anomalies of archaeological interest lie in a range of +/- 5 nT. Although the magnetic device operates with high reliability, due to the rough conditions of field-work, several systematic and unsystematic errors occur during data collection.

The first step in data processing is the correction of errors looking like spikes (fig. 2). These single spikes are due to failures of one sensor caused by low batteries, high temperatures (above 35° C) or physical shocks. They are detected in the image and replaced by the median of a 3 × 3 pixel surrounding. Variations in the height of the sondes above the surface are visible as line shifts. They are mainly due to surface roughness of ploughed soil or traces of tractors. Correction is done by detection of shifted lines and following equalization of the running line average.

Another kind of distortion is due to positioning errors of the moving sensors on the lines and appear as stripes (fig. 3). These dislocations are conspicuous in the results of nearly all magnetic prospecting teams and with our equipment and measuring process they occur in a maximum range of 0.25 - 0.75 m. They can be corrected by moving or stretching every second line up and down and computing a correlation measure. The final position of a column is reached at the minimal correlation measure. The result of this correction is a visible improvement of the image quality. These corrections are done automatically during the production of the image file. There are many reasons for these distortions and therefore we developed several methods of correction for the demands of the different range of positioning errors.

For further analysis the picture is inverted to get the anomalies of interest in dark grey tones. The next step uses the histogram of the displayed data to produce a higher contrast. For image enhancement the greyscale is stretched over the frequent data values. After the correction of the greyscale, brightness and contrast are tuned manually to improve visibility of the structures of interest. To reduce noise a median filter can be useful. Experience showed, however, that the corrected raw data without any filtering provide the best representation for the archaeological interpretation. Filtering always results in a loss of small archaeological details.

4 Evaluation of magnetic data

A method for the detection of anomalies by image processing is interactive thresholding. The following use of a contour tracing algorithm points out the anomalous zones. Yet, an interpretation only done by image processing techniques is not satisfying for archaeological purposes.

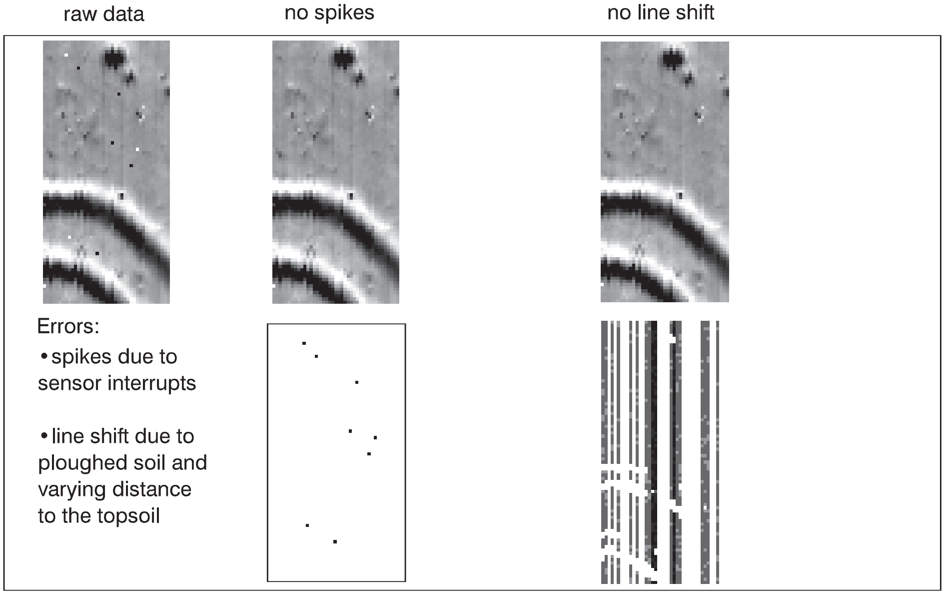

Figure 2. Correction of single spikes and the line shifts.

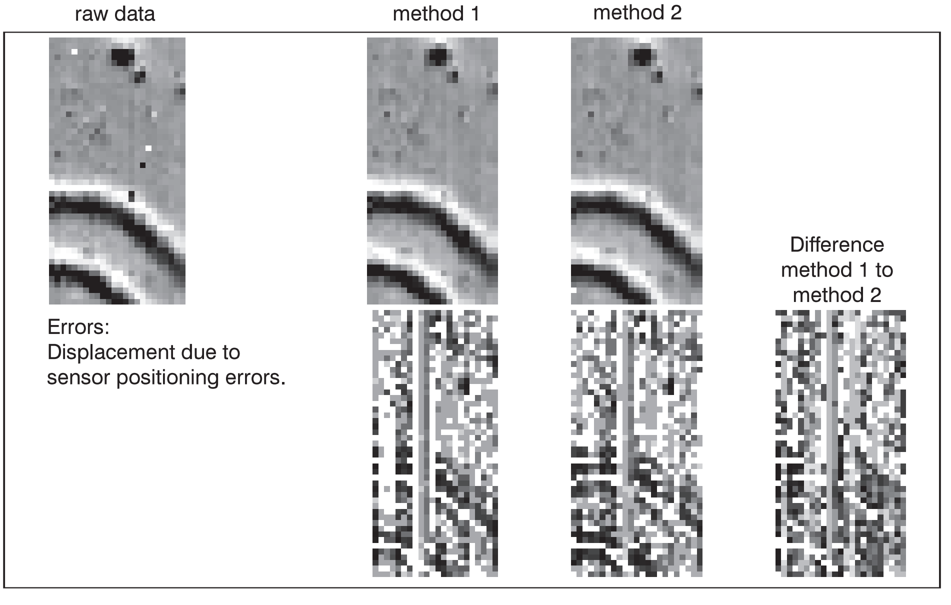

Figure 3. Correction of the displacements in the raw data.

An experienced interpreter is able to line out the archaeological features in a preprocessed image by mental comparison with excavated features. These features are frequently quite complex in shape and often have pronounced geometric forms. Superpositions of anomalies from different sources complicate the interpretation.

The boundaries of detected anomalies of archaeological significance are lined out on the screen overlaying the magnetogram. For the different features detected in the image we create various layers in different colours. Different thematic maps can be easily created from the interpretation layers. The mapped archaeological features

Figure 4. Magnetogram of Puch 1, corrected raw data, range [-7,3,2,7] nT → [white,black].

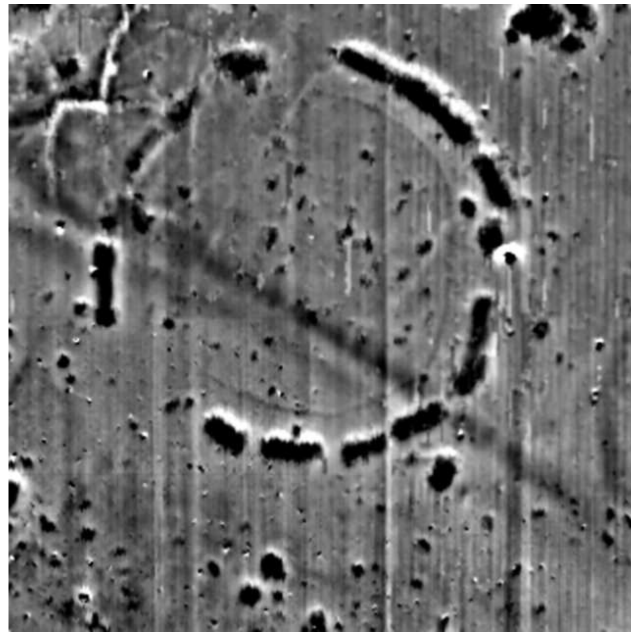

Figure 5. Magnetogram of Puch 2, corrected raw data, range [-5.3,2.7]nT → [white,black].

are then combined with the existing geodetic data by using CAD software (fig. 7). A primary requirement of the archaeologists with regard to geophysical prospection is to produce a presentation of the evaluated data which is understandable to anyone. The output as an interpretation map is a first step to reach this goal. Thus the end product is a map containing geographical information such as field boundaries, roads and contour lines together with the interpreted archaeological features from magnetic surveys. Later on excavation results are easily integrated into the general site context. For the high-resolution output of the magnetogram we use a 35 mm digital film recorder. The maps containing the interpretation are plotted on a A0 ink jet plotter. The produced maps are the most important basic information for the planning of consecutive excavations. In the following we will present three examples of magnetic surveys on large neolithic sites.[1]

4.1 Puch 1

The first example of a magnetic survey is a circular ditch system from the Middle Neolithic, from about 6500 years before present. The monument is known from aerial photographs (Fenster zur Urzeit 1982). The position and orientation of the entrances to the enclosure are of high interest. In the aerial photos they are fairly visible and for Puch 1 the interpretation assumed four entrances (Trnka 1991a). In the summer of 1994 an area of 120 × 120 m was magnetically prospected on a grid of 0.5 × 0.5 m.

In the processed magnetogram of Puch 1 (fig. 4) the two circular ditches are shown up very clearly. The magnetogram of the circular ditch delineates the feature outlines and shows many unknown details. Only two entrances were found in the east and west which are clearly visible. In the northern part of the interior a slight concentric anomaly can be detected. These are the last remains of a wooden palisade inside the enclosure. In the southern part of the magnetogram a decrease in the intensity and width of the ditch anomalies is an obvious sign of a bad state of preservation. Topsoil was removed from this area in modern times and filled into a washed-out river bed. The traces of the refilling are visible in the south of the surveyed area. Small anomalies all over the magnetogram are due to iron debris in the ploughed layer.

4.2 Puch 2

Only 160 m away from Puch 1 another circular ditch system is known from aerial photography (Fenster zur Urzeit 1982; Trnka 1991a). The second ditch system looks quite different from the other known monuments of the middle neolithic period and Puch 2 (fig. 5) was therefore thought to belong to a badly preserved Bronze Age settlement. In the spring of 1994 an area of 160 × 160 m was surveyed with a spatial resolution of 0.5 m.

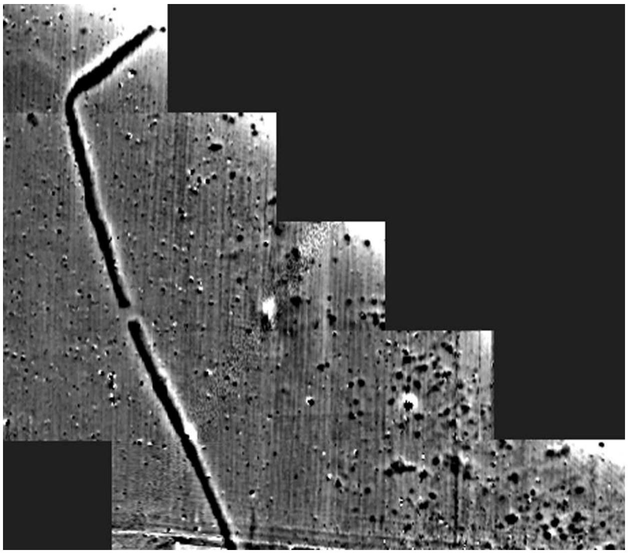

Figure 6. Magnetogram of Weinsteig, corrected raw data, range [-7.3,2.7]nT → [white,black].

The magnetogram shows an interrupted circular ditch. The concentric slight anomaly of a wooden palisade and new excavation results of other monuments underline a neolithic datation also for this ditch. Further research has to provide more information on that specific type of circular ditch systems. Around and inside the enclosure many pit structures were detected. Other anomalies are of geological origin or are due to the boundaries of the old fieldsystem before changing the orientation. These field boundaries respond as filled ditches.

The cross-sections of excavated circular ditch systems are triangular. That is the typical V-shape always observed with middle neolithic circular ditches. The excavated monuments showed that those ditches can be up to 6 m deep and up to 8 m wide. All have at least two and up to 6 entrances in specific orientations. Only well-preserved enclosures show concentric wooden palisades in the interior. Normally the posts were put into a small ditch. The filling of the ditches contains polychrome painted pottery (Lengyel) of high quality, animal bones and sometimes female statuettes. The enclosures must have been of cult use, for all kinds of rituals or meetings. Some have burial pits in the centre or pits with deer burials in the entrances. Because of the orientation of the entrances and lines of posts several prospectors and archaeologists suggest that they were also used for astronomical observations. Anyhow, these circular ditches represent the oldest and largest monumental structures known in European archaeology. Magnetic prospection is the most suitable method for the archaeological exploration of the 35 circular

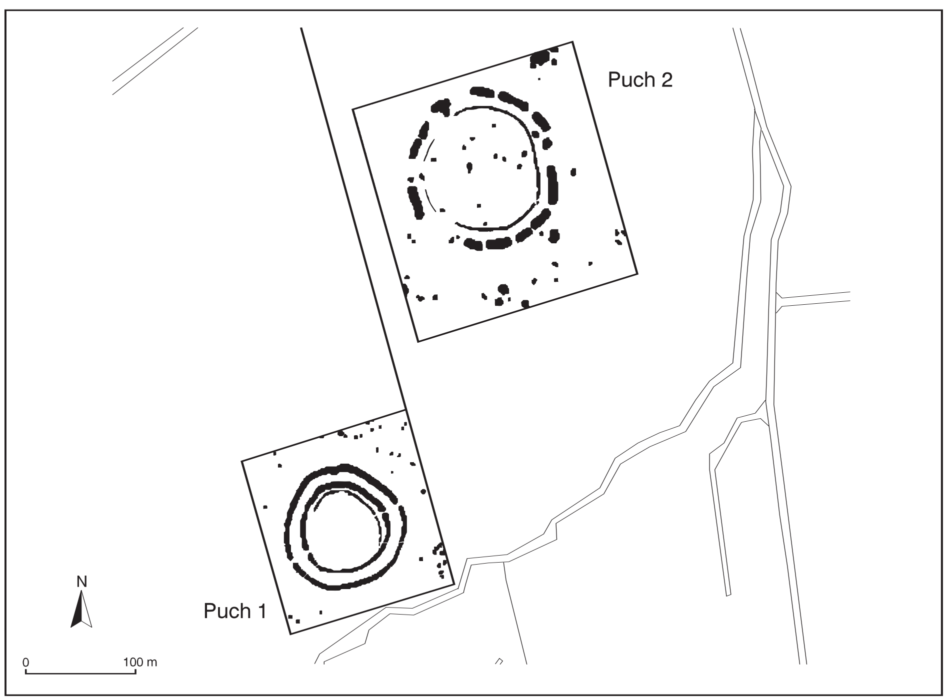

Figure 7. Interpretation map of the middle neolithic circular ditch systems at Puch.

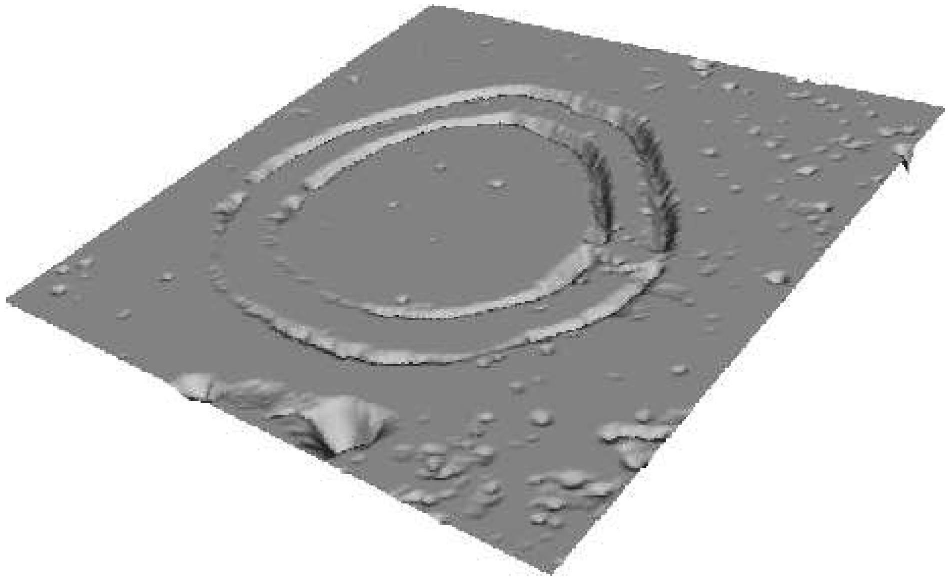

Figure 8. 3-D model of the reconstructed ditches and pits of Puch 1.

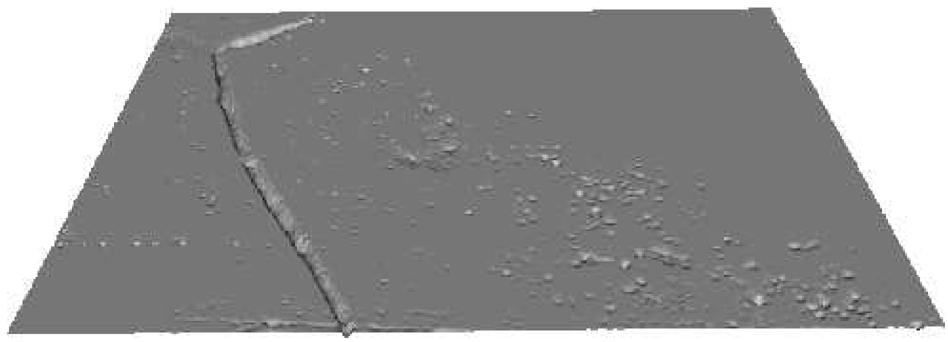

Figure 9. 3-D visualization of the reconstructed ditch and pits of Weinsteig.

ditch systems known in Austria (Melichar/Neubauer 1993; Trnka 1991a).

4.3 WEINSTEIG

Weinsteig is a fortified settlement known again from aerial photography (Fenster zur Urzeit 1982). The habitation is surrounded by a ditch of rectangular plan view with large dimensions of 725 × 350 m (Trnka 1991b). A first survey in the summer of 1994 (fig. 6) covered the northwestern part of the site with an area of 2.72 ha. The ditch is again clearly visible in the magnetogram and a first entrance could be discovered. Many structures, mainly pits can be seen inside the fortification. At this site massive erosion could be detected in the slopes. Only the flat top of the hill where the site is situated shows traces of habitation. Surface findings suggest an early neolithic datation for the extended monument (probably Late Bandkeramik). 3-D modelling of the ditch showed a U-shaped ditch (fig. 9) which seems to be typical of early neolithic fortifications. The surveys will be continued in the next few years.

5 Simulation and 3-D modelling

To understand the development of the prehistoric cultural and economic activities archaeologists try to obtain as much relevant information as possible. For this purpose, large numbers of similar sites must be identified, normally by aerial photography. Evaluation of further details can be done by non-destructive magnetic surveys prior to any excavation. Excavations are always coupled with an irreversible destruction of the investigated archaeological

Figure 10. Aerial photography of Puch combined with a plan view of the modelling of Puch 1 and the magnetogram of Puch 2.

structure. It is also the most expensive way of evaluating archaeological data. Therefore it is desirable to try and build a model of a monument including all relevant and known information prior to any excavation. In our case magnetic prospection data offers the possibility of reconstruction by modelling the subsurface. A model of the basic physical phenomena is constructed and changed until the measured data are accounted for with minimum error (Eder-Hinterleitner 1994). Prior to that, heuristics are used to separate components of the measurements due to archaeological sources from other than natural or modern origins. This is done by a classification algorithm which outputs a probability for each reading. The probabilities are used to separate archaeologically relevant anomalies from others.

The reconstruction algorithm is able to handle a survey of hundreds of thousands of readings at a calculation time of a few hours on modern workstations. The final result is a 3-D model (fig. 8) of the surveyed monument in a resolution of at least the used grid spacing. By input of a 3-D model, a magnetogram can be simulated. Variations of the primary model and the produced magnetograms can be used for training interpreters. The different outputs of magnetometry can also be combined with the aerial photography. In this example (fig. 10) we integrated the magnetogram of Puch 2 and a plan view of the 3-D modelling of the double ditch system of Puch 1.

6 Archiving

The ultimate goal of archaeological prospection is the generation of a visual information system based on all archived prospection data (Scollar 1990). Therefore, all relevant information including aerial photographs has to be digitized. For practical considerations we prefer orthophotos for archiving which are produced by combining digital elevation models and scanned images.

The digital terrain or elevation model (DEM) is measured directly from the aerial photograph with an analogue stereo-interpretation device (Kern DSR14) or with an automatic recording tachymeter in the field. The elevation data is rendered and combined with the outlined interpretations of archaeological features or is used as input to the orthophoto software. Scenic views can be produced by mapping the orthophoto on a perspective view of the digital elevation model. With this technique virtual views of monuments of thousands of years old again become available to archaeologists.

All data together form the basic information material of a database, *the prospection archive* of the Institute for Prehistory at the University of Vienna. For the realization of the already mentioned visual archaeological information system we use GIS-technology (ARC/INFO). From this information system the archaeologist can obtain results by searching either geographically, by type of site or by period. The information from the database and the evaluated aerial photographs or geophysical measurements can then be treated by methods of spatial statistics. That permits the analysis of associations between sites of similar and different types or periods, time or spatial trends and the significance of geographical distribution. Our ultimate aim is the realization of a visual geographic information system which can be used by anyone interested in the study or protection of the buried remains of our past.

note

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references

Doneus M. 1994 Datenbestände des Luftbildarchivs am Institut für Ur- und Frühgeschichte der Universität Wien, *GeoLISIII, Österreichische Zeitschrift für Vermessung und Geoinformation* 1+2, 119-124.

Eder-Hinterleitner A. 1994 Ein robustes Rekonstruktionsverfahren zur Bestimmung der Form von Gräben für die archäologische magnetische Prospektion. In: W.G. Kropatsch/H. Bischof (eds), *Tagungsband Mustererkennung 1994*, Informatik Xpress 5, 532-539.

Fenster zur Urzeit 1982 Katalog zur Sonderaustellung im Museum für Urgeschichte in Asparn an der Zaya. *Katalog des niederösterreichischen Landesmuseums*, Neue Folge 117.

Melichar P. 1990 Eine geomagnetische Prospektionsmethode im Dienst der Archäologie, *Aerial Photography and Geophysical Prospection in Archaeology, Proceedings of the second international Symposium Brussels 8-XI-1986*, 176-182.

Melichar P., W. Neubauer 1993 Magnetische Prospektion von Kreisgrabenanlagen in Niederösterreich, *Archäologie Österreichs* 4/1, 61-68.

Neubauer W. 1990 Geophysikalische Prospektionsmethoden in der Archäologie, *Mitteilungen der anthropologischen Gesellschaft in Wien*, Bd 120, 1-60.

Trnka G. 1991a Studien zu mittelneolithischen Kreisgrabenanlagen, *Mitteilungen der prähistorischen Kommission*, 124-126.

1991b Neolithische Befestigungen in Ostösterreich, *Mitteilungen der anthropologischen Gesellschaft in Wien*, Bd. 121, 137-155.

Scollar Irwin 1990 Archaeological Prospecting and Remote Sensing. *Topics in Remote Sensing* 2, Cambridge 1990.

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