Multi-antenna GPR data processing of the garrison of the governor's guard in Carnuntum/Austria

Alois Hinterleitner[1*], Mario Wallner[1], Ingrid Schlögel[1], Immo Trinks[2]

1 Near Surface Geophysics, Geosphere Austria, Vienna, Austria
2 Vienna Institute for Archaeological Science, University of Vienna, Vienna, Austria
* Corresponding author: E-mail: Alois.Hinterleitner@geosphere.at

Abstract
Multiple antenna GPR data provide excellent results when using 3d migration. 3d migration must be performed without erroneous measurements. 3d migration must be sensitive to the different channels. Wall structures along the measurement lines can then be visualized.

Keywords
archaeological prospection; ground penetrating radar; GPR data processing; GPR multi-antenna systems

Introduction

The recorded data of (motorized) GPR multi-antenna systems are different in several respects from those of GPR single-antenna systems and therefore require additional and more differentiated processing steps. Using single antenna systems every trace recorded is immediately visualized on the measuring device, thus enabling continuous quality control. Problems with the GPR antennas become visible and faulty measurement lines can be repeated immediately. The entire GPR data set is generated with one physical pair of antennas, so it has always the exact same transmission signal, the same influences of the measuring device setup and always an optimal ground coupling due to the smaller size of the antenna box. A single channel data set therefore usually has few errors and is very consistent in wave form and data quality.

The data quality of all channels of multi-antenna systems with 16 parallel channels, such as the Malå MIRA System available to ZAMG, on the other hand, cannot be constantly checked by the operator during the measurement. The individual antenna pairs are separate units and therefore behave slightly differently. They are mounted in different places in the measurement system and are therefore subject to different external influences due to the antenna box suspension and the towing vehicle. They sometimes have different ground clearance on uneven ground and sometimes a different, less than optimal ground coupling. In addition, the overall system is more complex and so more prone to errors. Therefore, the radar waveform is less consistent with multi-channel data sets and the data quality is sometimes lower because it contains more error values. This leads to increased demands on the processing software for multi-antenna systems, because the amount of data is much larger, the error correction is very sensitive, must happen automatically and the individual processing algorithms must be able to adapt to the different waveform and quality of the channels. If, in addition, a three-dimensional migration is to be carried out, disturbances in one channel affect several other channels, so that automatic error detection is of great importance. All processing algorithms must be implemented in such a way that they do not use single erroneous measurement points.

Data processing

Error detection

Error detection is carried out in several steps to detect different types of errors in the sequence of the severity of the possible error. First, traces without (reasonable) measured values and traces that show strong deviations in the first 2 ns

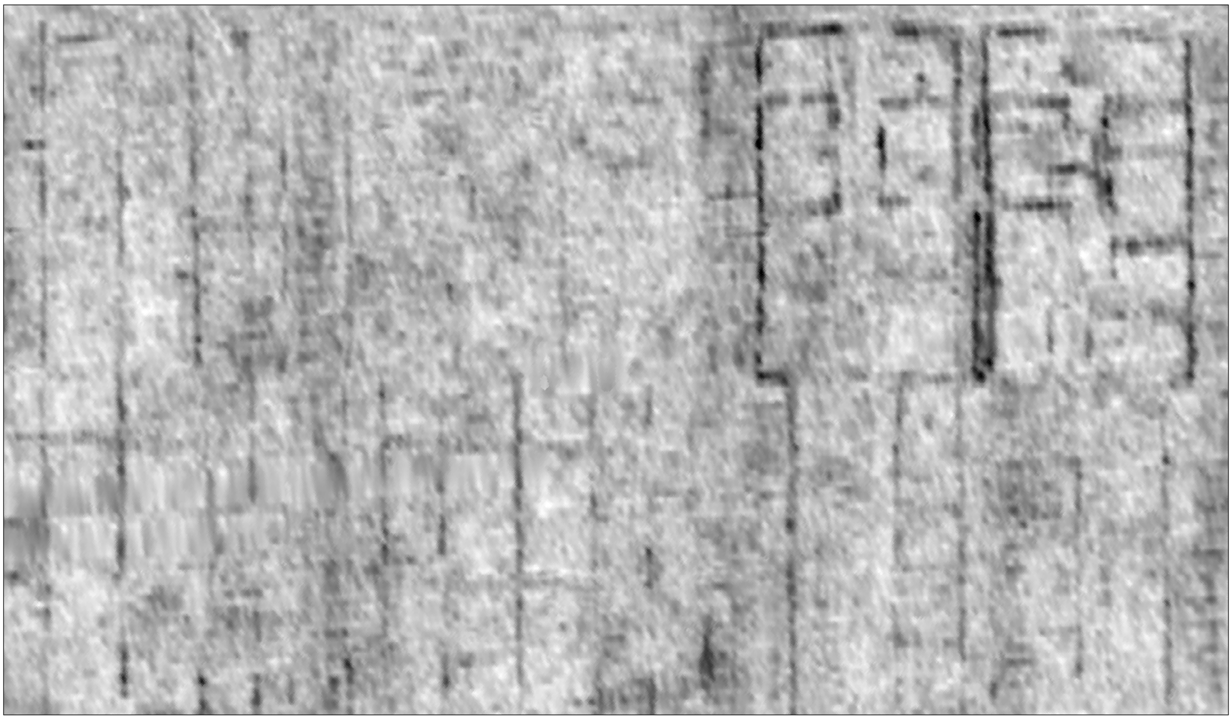

Fig. 1: GPR depth slice (80-140 cm) of an area of the garrison of the governor's guard; simulated single-channel survey with 50 cm line spacing; two-dimensional migration; area 43 m x 76 m. High amplitude reflections are shown in darker tones towards black and the survey data is orientated with north to the top of the page.

are detected. Both types of errors usually provide no measurement data, so these traces were completely removed. Then individual spikes are filtered out. Then the entire trace is divided into three sections and examined separately, because the ranges of possible error-free values differ greatly in these three sections. These three sections are, firstly, the direct wave section (around time zero), secondly, the mid-depth section with moderate energy loss, and thirdly, the section in the deeper areas from which very little energy returns. For the first section, the correlation is calculated with the same section of a mean trace determined by median calculation, since this section is dominated by the direct wave. Traces with low correlation are classified as faulty. For the other two sections, the envelope of the mean trace is calculated and used to set a limit for possible erroneous values. The limit of these two sections is usually higher for the second section than for the third. The samples of each trace are compared with these limit values and classified as faulty if exceeded. All faulty traces and readings are marked to be removed from further processing.

Time zero calculation

True time zero is not only very crucial for the depth estimation, but also very essential for the three-dimensional migration, which takes several channels into account. The first wave in turn is strongly dependent on the position of the antenna within the measurement system and can therefore vary greatly between the channels. In order to be as robust as possible here, the zero time is first calculated at an average trace calculated by median calculation. Then the zero time is calculated for each trace of this channel by correlation with the averaged trace.

Energy balance of the individual channels

The total energy of the individual channels can vary by up to 50%. An equalization by multiplication is carried out so that the energy of all channels is equal afterwards. This is absolutely necessary if several channels are used for one processing (three-dimensional migration).

Image processing

Due to the different ground coupling of the antennas in multi-antenna systems on survey areas with agricultural cultivation traces, there are often stripe-like patterns in the depth slices which, in addition, sometimes run exactly along archaeological structures. These patterns are eliminated or at least suppressed by a small-scale adaptation of the absolute amplitude values of an antenna channel to

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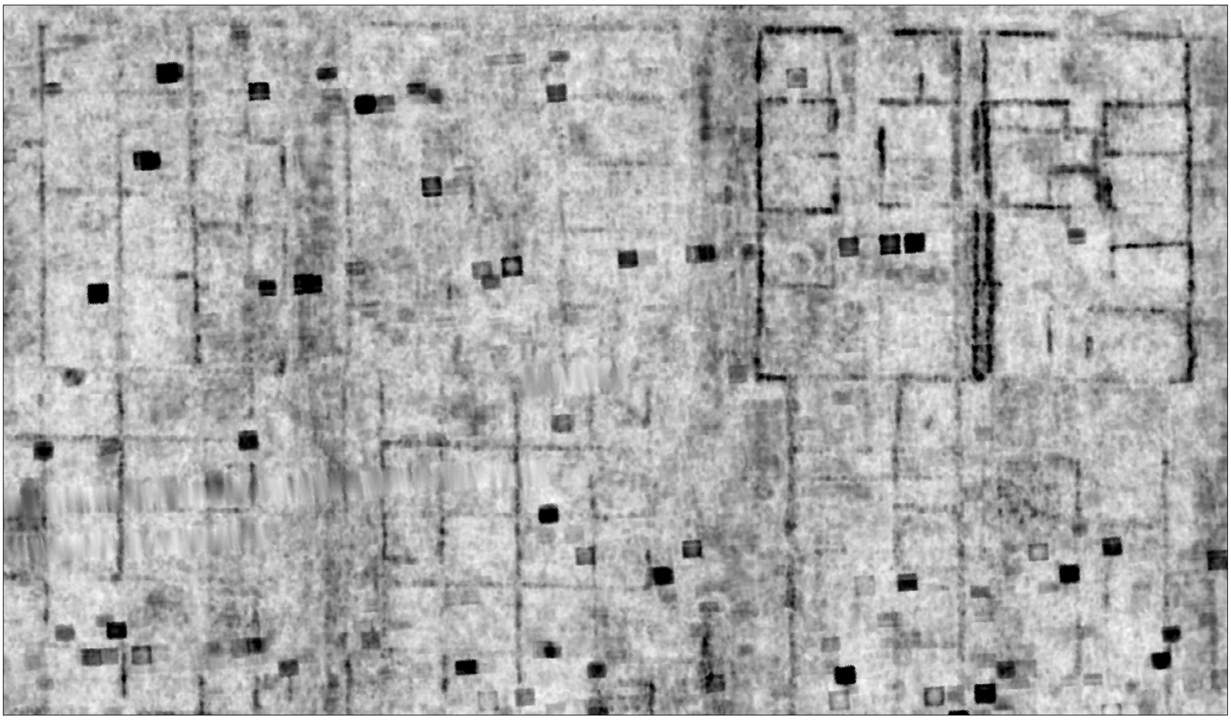

Fig. 2: GPR depth slice (80-140 cm) of an area of the garrison of the governor's guard; Malå MIRA survey with 10 cm line spacing; 3d migration without error detection; area 43 m x 76 m.

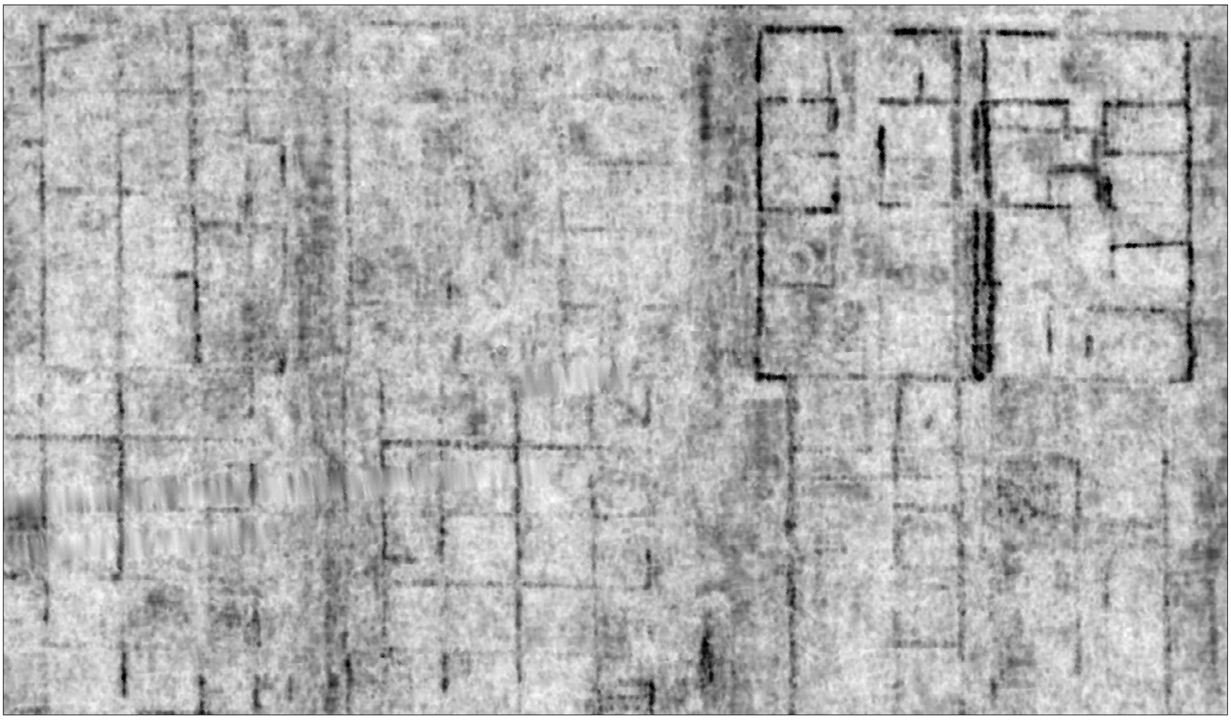

Fig. 3: GPR depth slice (80-140 cm) of an area of the garrison of the governor's guard; Malå MIRA survey with 10 cm line spacing; 3d migration with error detection; area 43 m x 76 m.

the neighboring channels in the direction of travel. Individual faulty values in the depth slices are also removed by a selective median filter in this last processing step.

Results of the Garrison of the Governor's Guard

The area of the garrison of the governor's guard at the Roman town of Carnuntum was prospected using a Malå MIRA multichannel system with 16 channels of 400 MHz antennas with 10 cm channel spacing. The measuring point distance is 2-5 cm depending on the surveying speed. This area includes a large military camp with rows of houses representing the barracks of the Roman soldiers. This unique military camp is part of the newly discovered administrative complex of the Roman province of Pannonia superior (Gugl et al. 2021).

A simulated 50 cm single antenna prospecting using only one fifth of the Mira channels is not able to show the walls along the measurement lines running east-west because the three-dimensional Kirchhoff migration is not better than the two-dimensional Kirchhoff migration (Moran et al. 2000) due to the large line spacing (Fig. 1).

The multichannel measurement with three-dimensional Kirchhoff migration, on the other hand, also shows the walls running along the measurement direction (east-west) very well. But without sufficient error detection, the individual erroneous readings appear through the three-dimensional migration as large interfering squares whose size corresponds exactly to the migration window (Fig. 2). Only processing with sufficient error detection and subsequent exclusion of the erroneous measured values during migration enables optimal visualization for detailed archaeological interpretation (Fig. 3).

Conclusion

In order to optimally visualize the data of multi-antenna systems, a three-dimensional migration must be performed. An optimal result can only be achieved if this processing can take into account the properties of the individual channels and exclude erroneous values.

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