3D GPR in Archeology: What can be gained from dense Data Acquisition and Processing ?

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***Abstract* - Most archaeological 3D GPR surveys suffer from a sampling bias: Spacing between GPR profiles is 5-10 times larger than trace spacing in profile direction. Such pseudo 3D GPR surveys produce highly interpolated subsurface maps which do not exploit the full resolution potential of GPR. This project was designed to answer the critical questions of how dense a GPR survey should be acquired and where are the resolution limits and bottlenecks of currently in archaeology widely used GPR hardware and processing software.**

***Keywords* – 3D GPR, Archaeology.**

I. INTRODUCTION

Present standards of 3D GPR in archaeological prospection are based on pseudo 3D methodologies which are characterized by a cross-line spacing which ranges from 0,25 m to 1 m (being 0,5 m the most common), the use of 250-500 MHz antennas and vast interpolation to fill-in the data gaps. Such methodologies along with powerful 3D visualization techniques are widely applied in GPR surveys with archaeological purpose [2, 5]. These surveys are usually image sites containing continuous linear features extending over several meters length such as foundations, ditches, walls, roads, etc. Most archaeological surveyors have not yet pushed GPR to its full potential and experienced the benefits of maximum resolution achieved with very dense data acquisition and processing. Hence the following question emerges: What is being lost by decimating data acquisition and applying data interpolation?

Ultra-dense 3D GPR honoring spatial Nyquist sampling theorem have already been successfully utilized to obtain unaliased 3D images of heterogeneous subsurface geometries such as: dune stratigraphy, tree roots and rock fractures. High resolution 3D images of the subsurface can be obtained if the space among traces is reduced to a quarter of the wavelength in the host material in all directions. In addition, a highly precise positioning of the GPR antenna during data acquisition is crucial, as it has been pointed out by other authors [4] and [6].

The currently prevailing paradigm that archaeological GPR datasets are already being gathered with enough density seems the main reason why the applications of ultra-dense 3D GPR methodologies are still limited in archaeological exploration. Besides, other geophysical techniques (such as magnetometry or resistivity), in adequate subsurface environments, can produce the same pseudo 3D image quality than GPR and resolve the main archaeological features in much less time (several hectares per day). However, archaeologists sometimes need to locate isolated features smaller than walls (i.e. objects, pits, postholes, burials or cisterns) [1].

Objective of this paper is to show how the extra effort in data-acquisition, refined methodology and processing can improve GPR imaging results. To directly relate the results to current practice, two identical ultra-dense 3D GPR surveys were acquired: One with standard GPR equipment using a low cost odometer wheel together with tape measures and strings as guidelines. The second survey was acquired with a next generation laser-positioned 3D GPR system developed at University of Miami [3]. Pseudo 3D datasets were generated by decimation of the dense surveys. Goal was to compare the efficiency of ultra-dense data acquisition, the accuracy of both equipments and the data quality.

II. METHODOLOGY

Figure 1. Test area at Ingraham Park, Miami, USA.

Figure 2. GPR system developed at University of Miami (left). Standard GPR equipment which was adapted for this comparison project (right).

3.1 Field Site and Data Acquisition

The test site consisted of a natural grassy area in a public park with tree roots, plastic pipes, old foundations and numerous buried small objects as in-situ imaging targets. Both tests used the same shielded bistatic 500 MHz antenna. As well same acquisition parameters were set: 600 samples/scan, 8 stacks, a sample rate of 6141 MHz resulting in a maximum two-way travel time of 98 ns.

The GPR data were acquired by pushing and pulling the cart and never turning the antenna. The survey area of 20 m x 12.50 m area was covered with 251 parallel GPR lines spaced by 5 cm recording a GPR trace every 2.5 cm in order to obtain two unaliased full-resolution 3D GPR surveys.

3.1.1 Odometer wheel acquisition:

After signposting with plastic pegs the grid corners, two measurement tapes were placed in the shorter pair of parallel sides of the grid for measuring the 5 cm spacing between the two survey tapes to mark the exact profile location. The person who moved the cart precisely followed the string in order to ensure straight profiles. Parallel to the survey tapes, two spray lines were drawn at a distance equal to the offset between the rear edge of the cart and the centre of the antenna. Thus the rear edge of the cart was used as a control point to start and end every profile consistently as shown in Figure 3.

Before starting surveying, the odometer wheel was calibrated for this terrain both in back and forward movement over 50 metres to maximize accuracy in both directions. To maintain a constant survey speed a metronome was utilized keep moving the antenna cart at the same pace throughout the survey.

3.1.2 Rotary laser acquisition

Novel rotary laser positioning system (RLPS) technology was integrated with GPR into an efficient 3-D imaging system [3]. The new system enables acquisition of centimetre-accurate x, y, and z coordinates from small detectors attached to moving GPR antennae. Laser coordinates streaming with 20 updates per second from each detector are fused in real-time with the GPR data. The person moving the GPR antenna is automatically guided by an array of LED elements along precomputed tracks following a dense lawnmower pattern to acquire parallel GPR profiles spaced by 5 cm covering the entire survey area.

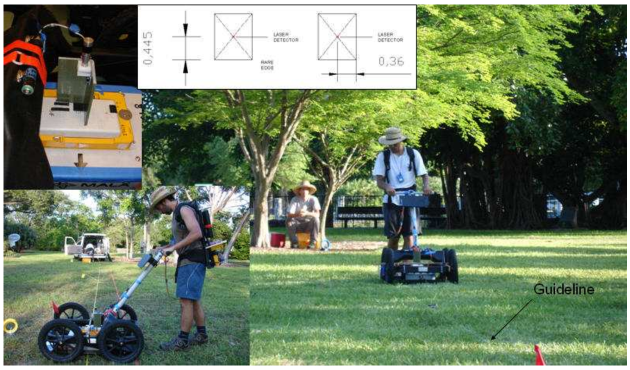

Figure 3. Methodology used with the standard GPR equipment: strings as guidelines for navigation, measurement tapes to place every profile and spray marks to help the operator to start and end each profile with better than 5 cm precision.

3.2 Basic Data Processing

For a direct horizontal slice comparison care was taken to exactly align the first breaks of both datasets. This Detrending and Zero-time adjustment step compensates for long- term instrument drift due to temperature changes by automatic picking of first breaks and applying spatially smoothed vertical shifts to traces. The same dewow and gain were applied to both the odometer and RLPS acquired data. The dewow step removes very low frequency components of the data. The gain curve is based on an averaged and smoothed Hilbert transform of a representative set of traces extracted from both 3D surveys.

3.3 Advanced Processing for 3D visualization

Pseudo 3D processing:

GPR-SLICE (c) v5.0 (www.gpr-survey.com) was developed for processing and visualization of pseudo 3D datasets. For this experiment we had to first decimate the dense odometer data. From decimated datasets (cross-line spacing: 0,5 m and 0,25 m) horizontal slices were generated by spatially averaging the squared wave amplitudes of radar reflections. Thickness of horizontal slices was set to 30 samples. The data were gridded using an Inverse Distance algorithm which includes a search of all data within a 0,75 m radius of the desired point to be interpolated on the grid and a smoothing factor.

Full-Resolution 3D Processing:

This processing sequence was applied to the dense 3D data acquired with the RLPS system. For the full-resolution 3D processing we use a combination of modules we developed in LabView (National Instruments) and, where mentioned, commercially available seismic processing software. The data processing consists of the following steps: Data fusion assigns laser derived x, y, and z coordinates to each radar trace acquired. Regularization populates a 2.5 cm x 5 cm bin grid with the nearest available trace. The horizontal resolution of the data was increased with the Promax (Landmark Graphics) 3D phase shift migration using a constant velocity field. The migration velocity of 0.08 m/ns was determined from diffraction hyperboloid analyses with ReflexW (Sandmeier Scientific Software).

IV. RESULTS

The comparison of the 2 methods revealed some interesting results: Data acquisition of the very dense 3D GPR survey with the conventional odometer system took 4 people more than 6 hrs while the same survey could be completed by 2 people in less than 4hrs using the laser positioned system. Subsurface maps generated by both surveys without neither interpolation nor decimation resolved the same targets (Figure 4). Despite of the fact that apparently there are not significant differences in the track-lines between surveys, the odometer survey contained random horizontal shifts (see Figure 5). The laser system produces a clearer representation of the subsurface target signatures.

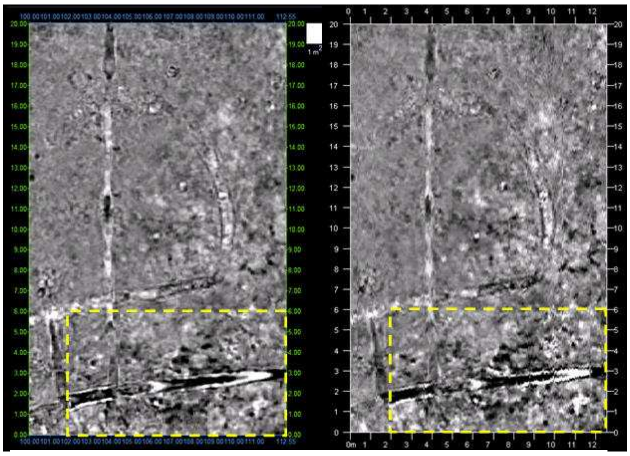

Figure 4. Unmigrated horizontal slices at 14 ns show plastic pipes and a part of the old foundations. Left: 3D GPR image obtained from the new generation RLPS positioned GPR system. Right: 3D GPR image obtained from the standard GPR system with odometer wheel. (Yellow dash lines indicate zoom-in captures that are shown below)

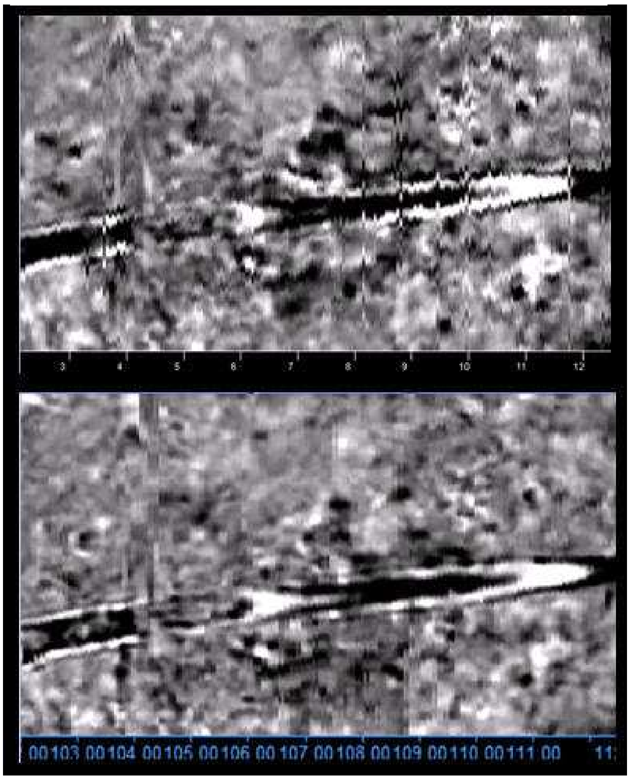

Figure 5. Zoom-in of images in Figure 4. Above: Random jitter noise caused by the odometer wheel acquisition is evident. Below: Laser positioned data shows improvements in image clarity when compared with the best practically possible result with conventional GPR equipment.

Decimation to wider line spacing and interpolation of the missing data shows how pseudo 3D GPR surveying blurs or misses many targets. Only the thickest tree roots can be seen and some of the linear signatures from pipes and foundations can not be identified as clearly (see Figure 6 and 7). As many of the small objects were only imaged by one line it becomes difficult to distinguish real targets from random noise.

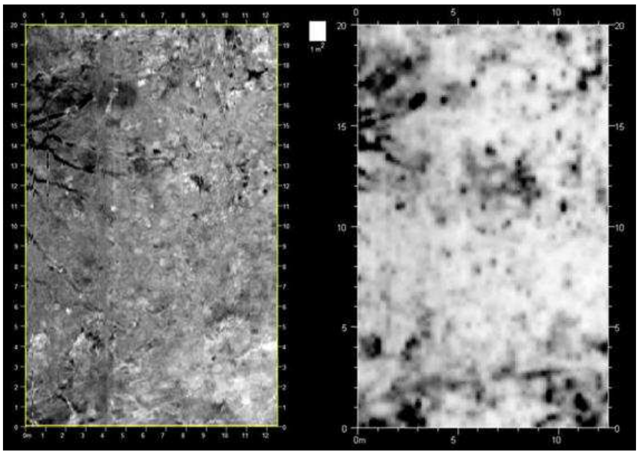

Figure 6. Unmigrated horizontal slices at 5 ns from the standard system. Left: Image obtained from GPR lines spaced 5 cm and non-interpolated 3D processing shows the tree roots. Right: Image obtained from GPR lines spaced 25 cm by using the pseudo 3D processing, the roots are almost invisible.

V. CONCLUSIONS

Overall, the current practice of producing archaeological subsurface maps with 3D GPR has still lots of untapped potential. The GPR map resolution can be improved by acquiring denser than quarter wavelength data in all directions and avoiding interpolation and decimation processing schemes. Faster 3D data acquisition equipments plus precise positioning systems are important future needs in archaeological geophysics. While PCs and graphics cards are already powerful enough, most current commercial GPR software tools are unfortunately not yet suitable for processing of such dense datasets. For the data example shown in this paper 3D migration in RefleW would have been only possible after reducing the data to half the samples in time direction.

However, a little unexpected but encouraging was the result of this experiment in terms of how much detail can be captured on unmigrated data acquired very densely with the odometer wheel. Even a low-cost odometer wheel positioned GPR system coupled with a large data acquisition effort can produce usable full-resolution 3D results. However, to achieve crisp GPR maps free of acquisition jitter noise, centimetre precise coordinates for all GPR traces are a requirement.

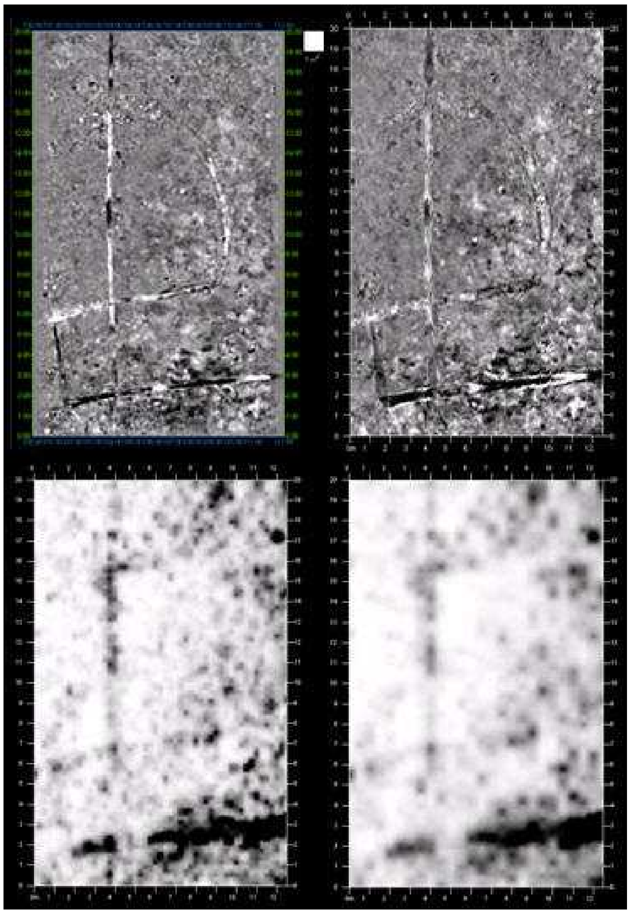

Figure 7. Images at 14 ns. Upper-left: migrated slice from full-resolution 3D processing. Upper-right: unmigrated slice from non-interpolated, non-decimated data recorded with the odometer wheel system. Both show plastic pipes, irrigation lines and old foundations. The last two images show how data decimation to coarser cross-line spacing (25 cm, left and 50 cm, right) plus the pseudo 3D processing method degrade the resulting image which becomes blurrier until losing the targets.

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