Modelling for 3D migration of GPR data

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ABSTRACT

The acquisition of 3D ground penetrating radar (GPR) is accomplished by shooting a number of 2D lines across the target area. Typical processing of this data includes 2D migration of each line followed by interpolation to a 3D grid. This process produces high resolution of the subsurface along the 2D lines, but poor resolution between these lines. My intent is to model the acquisition process to identify features that may improve the 3D resolution.

INTRODUCTION

Ground penetrating radar (GPR) uses a dipole antenna for both the source and receiver. The radiation pattern for a dipole antenna in uniform media is shaped like a donut whose axis of symmetry is in the direction of the antenna. Placing the source and receiver antenna on the surface of the Earth distorts the radiation pattern significantly, Butler (2005). Visualizing the donut shape aids in discussions of how to orientate the antenna relative to the direction of acquisition.

In typical GPR acquisitions, the antennas are orientated normal to the direction of the 2D acquisition line (like a wheel on a wheel barrow). In this mode the energy is directed to the vertical plane of the acquisition line maximizing the inline energy. This orientation is appropriate for 2D migration of the line and it also minimizes sideswipe energy.

Current 3D projects are acquired with many 2D lines that are 2D migrated then interpolated using a number of different techniques.

My objective is to perform a 3D migration of the data. I have developed a few models so that we can compare 2D migrations then interpolation with 3D migrations.

Kirchhoff migration

Kirchhoff migration sums energy along a diffraction shape and places the energy at the apex of the diffraction. It has many advantages over alternate methods. It can easily deal with arbitrary input geometries and migrate to any desired geometry. It can also economically migrate data with a fixed source-receiver offset. A specific advantage for 3D Kirchhoff migration, when applied to 3D-GPR, is its ability to migrate aliased data.

CONSIDERATIONS FOR 3D MIGRATION.

Some of the following points have been discussed with fellow professionals and represents some form of consensus.

1. Vary the orientation of the antennas to illuminate offline reflectors. The offline energy is normally attenuated deliberately to enhance inline imaging. However, when trying to recover reflectors between the 2D lines, we will require their reflection energy.

2. To prevent aliasing, the spatial sampling along the 2D line is usually adequate and should use parameters that conform to the aliasing equation, i.e. the trace interval δx should be less than

$$\delta x_{\max} = \frac{V}{4 f_{\max} \tan\theta} \qquad (1)$$

   where V is the velocity at the scatterpoint, f_{max} the maximum frequency of the wavelet, and θ the dip angle, before or after migration.

3. The distance between the 2D lines is the main problem for forming a 3D image of the subsurface. Any distance that does not conform to equation (1) will produce aliasing. The closer the lines the better the interpolation and migration. An important point to note with GPR data is that the velocity decreases with depth and that the migration aperture will become narrower with depth. Consequently the distance between lines should consider the velocity when imaging deeper objects. Acquiring orthogonal 2D lines will greatly aid in the imaging.

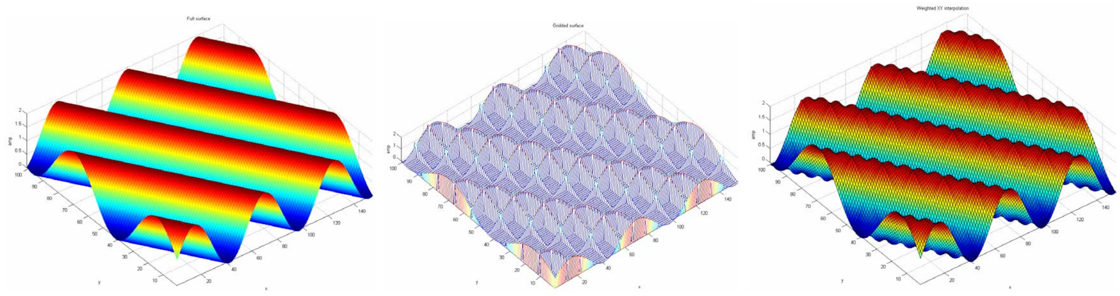
4. Antialiasing filters are used with Kirchhoff migration to reduce noise from aliased energy. It is possible to migrated the aliased energy along with the unaliased energy to preserve an aliased migrated event. A consequence of including the aliased energy is that it is also migrated as noise. Testing continues to evaluate potential signal to noise ratio.

5. When processing conventional seismic data, it is better to interpolate the data before migration. Dips before migration are limited to 45^o while after migration the dips can be up to 90^o. Interpolation can also add dipping energy that exceeds the 45^o dip limit that will be removed by the migration.

MODELS DESIGNED TO EVALUATE INTERPOLATION

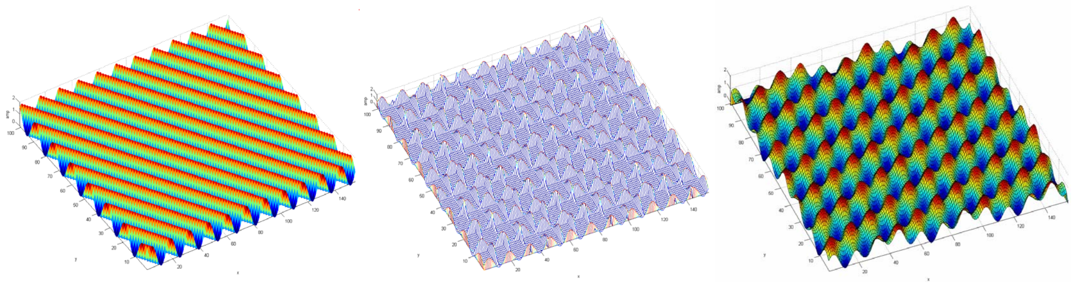
Models were designed to evaluate 3D interpolation of 2D migrated data. Figure 1 contains three images that represent (a) a sinusoidal surface, (b) the sinusoidal surface mapped to a grid of 2D lines, and (c) a linear interpolation of the 2D line data that should match the original input data. A weighted linear interpolation was used for a reasonable match.

Figure 2 contains a sinusoidal surface with a higher frequency. The frequencies of this surface were chosen so that when mapped to the 2D grid, the frequencies were aliased. Note how the aliased data on the 2D grid can not recover the original surface.



a) b) c)

FIG. 1. Illustration of interpolation, a) a sinusoidal surface, b) a 2D grid formed from the surface and c) the interpolation of the grid.

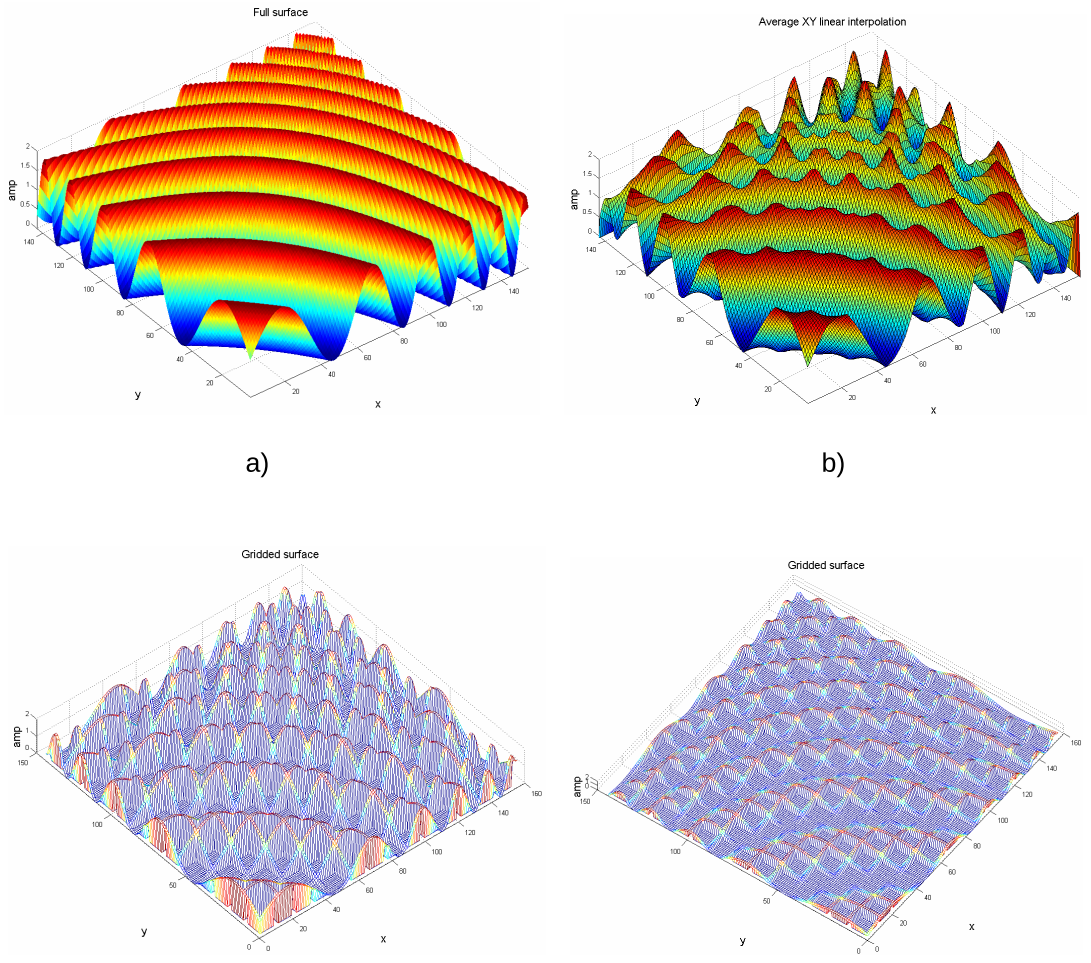


a) b) c)

FIG. 2. Illustration of an aliased interpolation, a) a sinusoidal surface, b) a 2D grid formed from the surface and c) the interpolation.

A third model shown in Figure 3a was constructed to contain a range of frequencies that would produce unaliased and aliased data. It also included circular shapes that could evaluate the interpolation of different orientations. The original surface is mapped to (c) and (d) and the interpolation in (b) was formed using an average of linear interpolation in the *x* and *y* directions. It was difficult to display the gridded data, so two orientations of the same data are shown in (c) and (d).

Note how the interpolation is reasonable for the lower frequency data, but unreasonable for the aliased data. All other interpolation schemes that were tested produced results that were either similar to, or worse than, those in Figure 3b.



a) b)

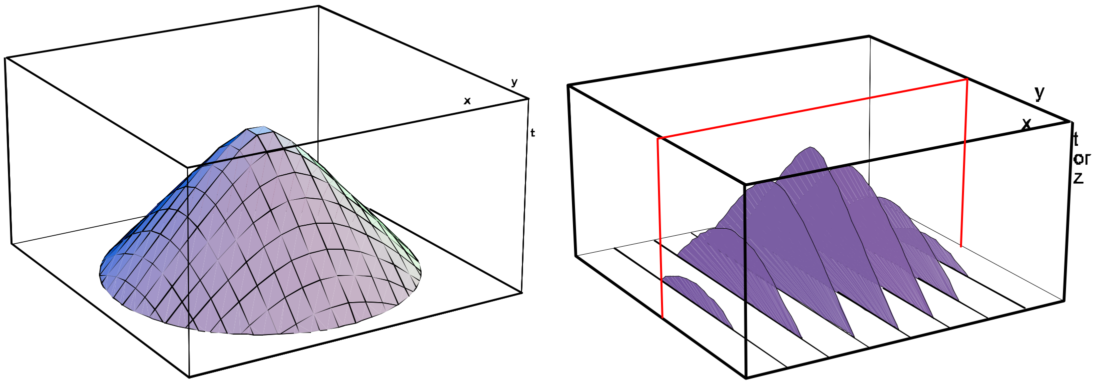
c) d)

FIG. 3. A modelled surface in a) contains varying frequencies with different orientations .Parts c) and d) show two views to the data mapped to the 2D grid. The interpolation is in b).

MIGRATION MODEL

A simple model was created to evaluate a 3D migration of data formed from a 2D grid. A single scatterpoint was chosen that has a 3D diffraction shape of an hyperboloid as illustrated in Figure 4a. The mapping of this energy onto parallel 2D lines (b) shows hyperbolic diffractions. Consider a 3D migration of this energy in which energy in all possible hyperboloids is summed to the apex of each hyperboloid. If there is only one scatterpoint with the diffraction shown in Figure 4a, then all the energy on that surface is summed to the apex. Energy will also be summed to all other points in the volume, but will cancel if the data complies with the restrictions of equation (1).

Consider now the aliased form the hyperboloid in Figure 4b. Energy from the 2D diffractions will sum to the apex of the hyperboloid, but will also be migrated to all other locations in the volume. This energy will not cancel everywhere as the criteria defined by the aliasing equation are violated. (The energy actually spreads to a 2D semicircle that is orthogonal to the diffraction.)



a) b)

FIG. 4. A 3D diffraction in a) has the shape of an hyperboloid, which when projected onto a series of 2D lines b) produces 2D hyperbolic diffractions on the 2D lines.

An example of a 3D migration of the 2D line model in Figure 4b is shown in Figure 5. This figure is one 2D line taken from the center of the migrated volume. It is normal to the 2D lines and passes through the scatter point. Note that energy from the 2D diffractions does focus at the apex as desired. However, the energy also moved to other locations and is not cancelled but remains as aliased noise. Another disappointing feature of this figure is the energy from the distant 2D lines are contributing little energy at the location of the scatterpoints as indicated by the amplitudes along the migration smiles.

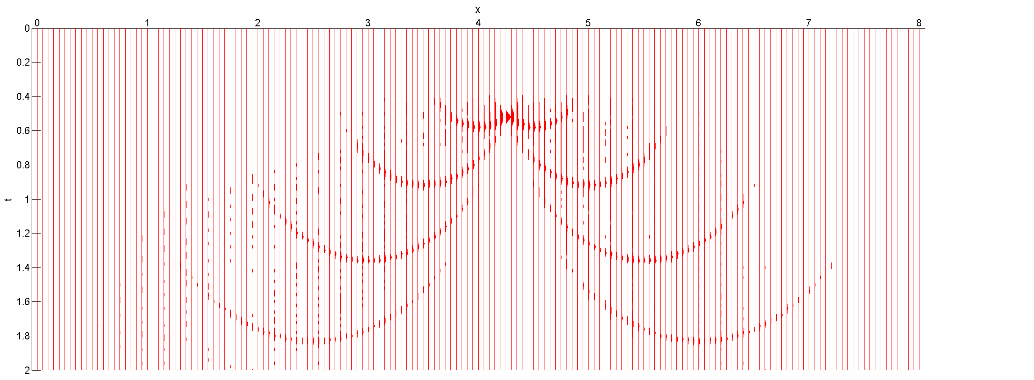


FIG. 5. A 3D migration of an hyperboloid mapped to a number of 2D lines.

The small amounts of energy from the distant 2D lines indicate that the imaging could be improved by limiting the migration aperture and that steeper dips will be more difficult to image.

A PERMANENT TEST SITE

Numerical modelling will help quantify some design and processing parameters, but we really need to develop a test site that contains known objects and their locations. Such objects could be 50 gallon containers with various orientations, short and long lengths of rebar, point reflectors, gallon cans, or even some concrete steps. These objects could be placed in a constant medium such as sand or could include various layered material. It would also be desirable that the site could be covered to control moisture content and that it have the ability to control the depth of water within the site.

The test site would provide valuable information that could be compared with the imaging results from surface GPR.

CONCLUSIONS

There is much that can be done to improve the imaging of GPR data that is collected to image of the 3D subsurface. Possible improvements include alternate orientations of the antennas with respect to the 2D lines, and 3D Kirchhoff migrations that migrate aliased data.

Models were presented to evaluate the interpolation of gridded 2D data to 3D data. It was shown that interpolation after migration is really limited by the dimensions of the gridlines.

A permanent test site would also be valuable in comparing imaged results with known structures

REFERENCES

Butler, D. W., 2005, Near-Surface Geophysics: IG No. 13, SEG