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A software toolset for processing and visualization of single and multi-offset GPR data

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Summary

Processing Ground Penetrating Radar (GPR) data is essential to assist with interpretation, the reduction of unwanted noise, and to highlight information relating to the purpose of a survey. Currently, the majority of GPR data processing software is coupled together with GPR hardware systems from the manufacturers, and often at an additional cost. These software packages often incorporate simplified or limited processing methods, and they do not allow the processing of data generated by GPR systems of different manufacturers.

We present a MATLAB-based software with a user-friendly graphical user interface (GUI) for the visualization and processing of GPR data. The software supports file formats from a wide variety of GPR manufacturers, and can handle both single-fold (SF) and multi-fold (MF) GPR data. The software is capable of applying standard workflows, but one of its key features is novel processing algorithms for MF GPR data, especially from the new multi-concurrent sampling receiver GPR systems. These algorithms are more commonly used in seismic data processing and have not previously been applied to GPR data from these systems.

Introduction

GPR is a high frequency electromagnetic (EM) inspection technique which is used for the detection of electrical discontinuities in the shallow subsurface. The non-invasive nature of GPR as well as its ability to provide very fast, high-resolution data and on-site feedback, has made it a particularly popular method for a wide range of near surface applications. Nowadays, these applications vary from planetary exploration (Tosti and Pajewski, 2015) to the detection of landmines (Tellez and Scheers, 2017).

Processing GPR data is essential as it can highlight information related to the purpose of the survey. There are many cases in which the subsurface features of interest are detectable from the raw data. Processing, however, can be used to amplify the recorded signals, reduce unwanted noise, and consequently produce a final image which is not only more easily interpreted, but also more understandable and presentable to the end-user or client. Processing is also inevitable in the case of multi-offset GPR data in order to extract the desired subsurface information, such as the EM wave propagation velocity.

Similarly, image reconstruction techniques can play an important role in interpreting the data as well as presenting it. Generally, GPR data are recorded in the form of one-dimensional (1D) signals, known as traces. The collected traces can undergo different coordinate transforms and can also be visualized in several different ways in order to provide subsurface information in both horizontal and vertical directions, allowing us to “see the unseen” (Wai-Lok Lai et., al, 2018). Typical visualization methods include two-dimensional (2D) reflection profiles, three-dimensional (3D) volumes, and time/depth slices.

Nowadays, most GPR data visualization and processing software, are proprietary, and provided with the GPR system itself, by the same manufacturer, and often at additional cost. Moreover, these software packages cannot be used to process data generated by GPR systems of different manufacturers, and usually have simplified and/or a limited range of processing tools (especially for MF data) as their use is mainly intended for people not fully experienced with the GPR and/or the seismic reflection method, from which many GPR processing techniques have been adopted.

MATLAB (Mathworks.com, 2020) is a high-level scripting/programming language, generally easy to master due to its simple syntax, and widely used in academia for visualizing and analyzing different kind of engineering and scientific data. MATLAB offers a rich toolbox set for matrix manipulation and mathematical tasks, has a highly active community, and supports the development of scientific analysis applications that integrate GUI in a variety of ways such as visual design environments (e.g. GUIDE, App Designer).

In this work we present a MATLAB-based software with a user-friendly GUI for visualizing and processing GPR data. The software supports various file formats from different GPR manufacturers as well as the ability to handle simulation data from gprMax (Warren et., al, 2016). It consists of three different modules: the main 2D module which can handle both SF and MF GPR data including from newly developed GPR systems with multi-concurrent sampling receivers (Diamanti et al., 2018); the common mid-point (CMP)/wide-angle reflection-refraction (WARR) velocity analysis module which incorporates an interactive GUI tool, different types of velocity spectra as well as stacking methods; and the 3D module for creating 3D volumetric data and time/depth slices.

GPR data visualization and processing software

2D Module

The 2D module can be considered the heart of the software toolset, since under certain conditions, such as the number of data files imported or the acquisition mode of the data, it can also provide access to the other two modules, namely the CMP/WARR velocity and the 3D module. Furthermore, depending on these conditions, additional buttons, panels or menu options can be enabled or disabled in its GUI to facilitate the handling and processing of the data. Figure 1 depicts the GUI of this module in its simplest form for a SF GPR dataset. As can be seen it consists of five different elements:

1. The menu bar from which the file I/O, data analysis, processing and imaging options can be accessed by the user.
2. A panel for the visualization of the raw data or data from the previous processing step.
3. The info/header panel that displays the different data acquisition parameters, such as the number of samples, traces, sampling interval, etc.
4. A separate panel for the visualization of the data of the current processing step.
5. The workflow panel from which the user can access and visualize, undo or restore the data to a previous processing state, and can save the processing procedure in a text file (.prc) that can be used for batch processing.

The file menu enables the file I/O operations. Different data file formats from a wide variety of GPR manufacturers can be imported, exported, converted, or even combined under certain circumstances (i.e., when they have the same acquisition parameters) in one file. The file formats supported are shown in Table 1. In addition, this menu enables the batch processing of multiple datasets using the aforementioned .prc file that can be generated through the workflow menu.

The analysis menu provides several functions for analyzing the GPR data. These are categorized as the frequency spectrum analysis, frequency-wavenumber spectrum analysis, signal attenuation analysis, fold analysis, and the velocity curve-fitting analysis which incorporates an interactive tool for the curve matching technique. Moreover, depending on the conditions through this menu the user can also access the other two modules of the software toolset.

Table 1: Software supported file formats.

Developer	File extension
gprMax	.out
GSSI	.dzt, .dzt
Impulse Radar	.iprb, .iprh, .cor
Måla	.rd3, .rd7, .rad, .cor
MATLAB	.mat
Sensors & Software	.dt1, .hd, .gp2
Society of Exploration Geophysics	.sgy

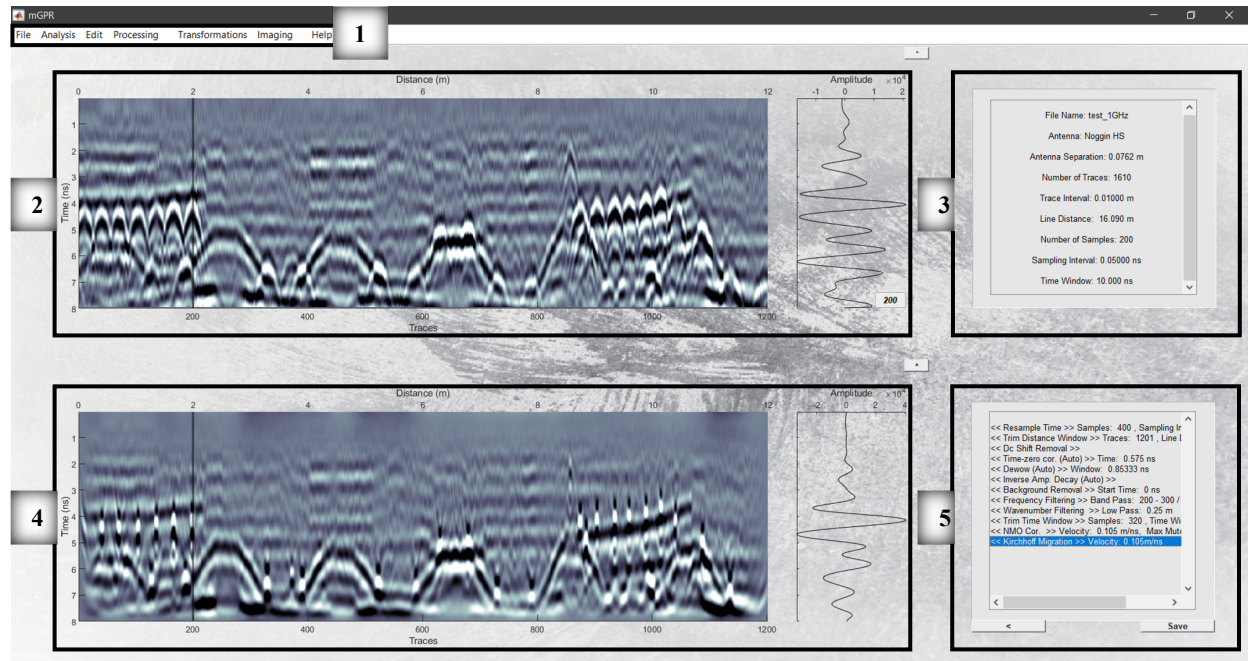


Figure 1: GUI showing the main elements of the 2D module for SF GPR data: 1. Menu bar, 2. raw or previous processing step data panel, 3. header/info panel, 4. current processing step data panel, 5. workflow panel.

GPR data visualization and processing software

Regarding data processing, the 2D module comprises many different simplified as well as advanced processing techniques that can be accessed through the edit, processing, and transformation menus respectively (Table 2). Some of these techniques, for instance dewow, can also be performed automatically, while most of them, such as the AGC, provide additional options (e.g. instantaneous or rms AGC, separate or average gain function) through pop-up windows.

Lastly, the imaging menu contains all the data visualization tools which includes, display interpolation, different colormaps, color saturation/contrast, and wiggle trace plot.

Table 2: Processing methods of the 2D module for SF GPR data

Edit	Processing	Transformations
<ul style="list-style-type: none"> ▪ Time-zero cor. ▪ Reverse X-axis ▪ Declip ▪ Resample <ul style="list-style-type: none"> ▫ Time ▫ Distance ▪ Mute <ul style="list-style-type: none"> ▫ Area ▫ Traces ▪ Direct wave ▪ Trim <ul style="list-style-type: none"> ▫ Time ▫ Distance ▪ GSSI gain rem. 	<ul style="list-style-type: none"> ▪ DC-shift rem. ▪ Dewow ▪ Time gain <ul style="list-style-type: none"> ▫ AGC ▫ IAD ▫ Power ▫ Custom ▪ Background rem. ▪ Frequency fit. ▪ Wavenumber filt. ▪ Horizontal ▪ Deconvolution ▪ NMO cor. ▪ Migration <ul style="list-style-type: none"> ▫ FK ▫ Kirchhoff 	<ul style="list-style-type: none"> ▪ Depth ▪ Topography ▪ Mathematical <ul style="list-style-type: none"> ▫ Absolute ▫ Derivative ▫ Logarithm ▫ Square ▪ Phase shift ▪ Hilbert <ul style="list-style-type: none"> ▫ Amplitude ▫ Phase ▫ Frequency

CMP WARR velocity analysis module

The CMP/WARR velocity analysis module can either work independently or in combination with the main 2D module, i.e., the processing steps applied to the latter are also applied to the former. Since velocity analysis as a procedure is highly interactive and many times requires constant trials or parameter changes, we have followed a different approach for the GUI development of this module. In contrast to the 2D module, all the data visualization and processing options are placed in the main window, while any parameter change is directly reflected on all the panels of the GUI. The GUI is illustrated in Figure 2 and as can be seen it consists of six different elements:

1. The file menu which controls the file I/O operations, including exporting the interpolated stacking or/and interval velocity cross section, and the final stacked section.
2. The velocity spectra panel which incorporates an interactive tool for assisting the velocity picking process.
3. A panel for displaying the 1D velocity produced by the analysis versus the calculated interval velocity.
4. The CMP gather panel.
5. A panel for the visualization of the stacked trace versus a reference trace of the selected CMP gather.
6. A panel for displaying the 2D stacked section overlaid by the interpolated stacking velocity cross section.

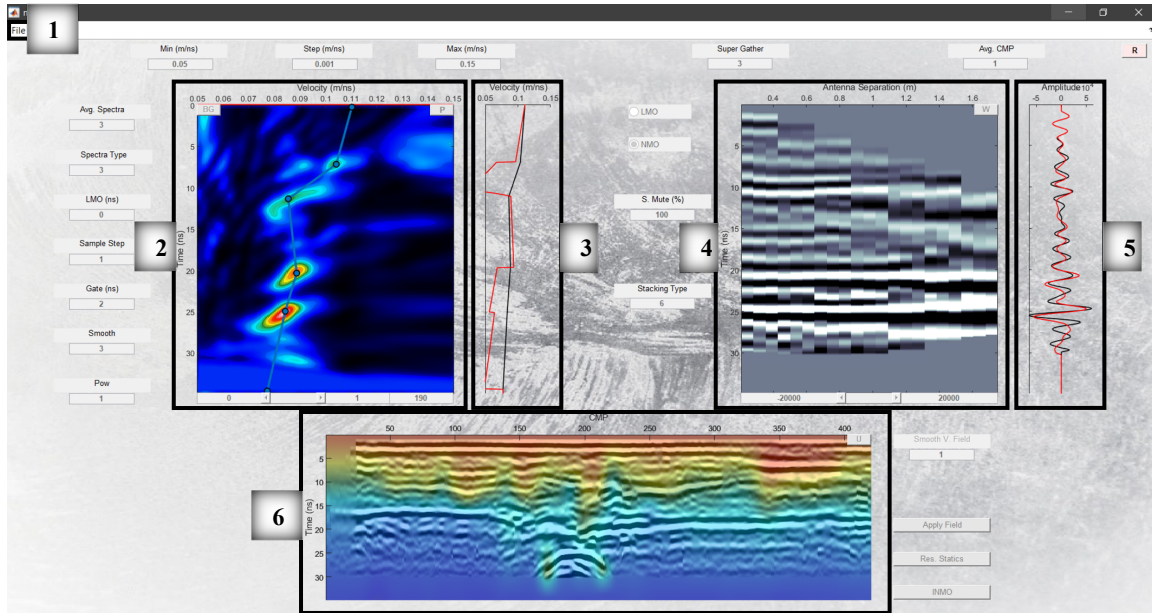


Figure 2: GUI showing the main elements of the CMP/WARR velocity analysis module: 1. File menu, 2. velocity spectra panel, 3. 1D velocity panel, 4. CMP gather panel, 5. stacked trace panel, 6. stacked section/interpolated stacking velocity cross section panel.

GPR data visualization and processing software

The module supports many processing steps (some of which are more advanced and have their basis in seismic reflection data processing) such as: CMP sorting, CMP averaging, super CMP formulation, CMP balancing techniques, linear and normal moveout (LMO, NMO) correction, stretch mute, as well as residual statics correction. It also incorporates different coherency measures for computing the velocity spectra including: normalized stacked amplitude, unnormalized cross correlation sum, and semblance (Yilmaz and Doherty, 2010), while it also allows the computation of combined LMO/NMO spectra, as well as spatial spectra averaging. Lastly, several stacking methods for a final stacked section are integrated into the module such as mean, median, alpha-trimmed, and smart stack (Rashed, 2008).

3D module

The 3D module is specifically designed for creating, manipulating, as well as visualizing 3D GPR data sets. Currently it can only work with GPR lines measured in a rectangular grid, but further development is planned to extend the functionality. Similarly, as the aforementioned CMP/WARR velocity analysis module, the 3D module is also interconnected to the main 2D module and incorporates a very simple GUI the main elements of which are described below and shown in Figure 3 (top). To avoid having additional panels, buttons, or sliders for zoom, rotating options etc. integrated into this GUI, we chose to use a separate MATLAB figure for the visualization of the 3D data set as it is observed in Figure 3 (bottom). This module consists of the following three elements:

1. The file menu which controls the file I/O operations.
2. The gridding options panel for creating the 3D data set.
3. The 3D visualization panel which includes buttons and sliders for all the visualization options.

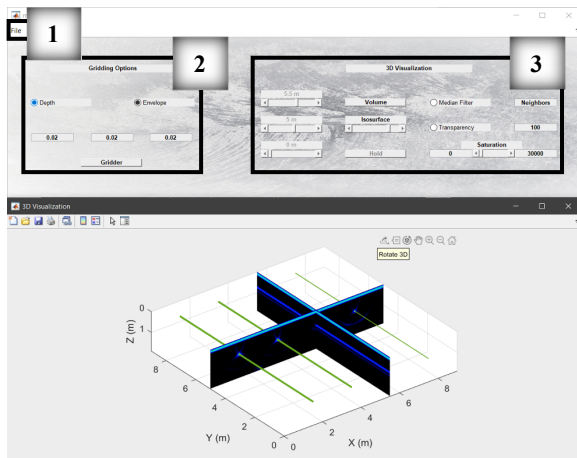


Figure 3: GUI showing the main elements of the 3D module: 1. File menu, 2. gridding panel, 3. 3D visualization panel.

The 3D module supports the visualization of 3D volumes, isosurfaces, and 2D time/depth slices. In addition, it supports export of both slices and volumes in CSV data format for visualization and processing with third-party software such as Golden Software's Surfer and Voxler.

Conclusions

We have developed a software for the visualization and processing of GPR data. It includes many common GPR processing steps but is focused around advanced algorithms we have implemented for processing MF GPR data from multi-concurrent receiver GPR systems. The user-friendly GUI was created using MATLAB, and the toolset supports file formats from different GPR manufacturers. It consists of 3 different modules that can work either independently or together: the 2D module can handle both SF and MF GPR data, and allows simple and fast control of the processing workflow, as well as batch processing; the CMP/WARR velocity analysis module incorporates an interactive GUI tool, and many advanced processing steps for MF GPR data; the 3D module supports all the typical 3D data visualization methods as well export of data in formats for visualization and processing with third-party software.

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