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PREPROCESSING OF GPR DATA

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Abstract. In this article a set of procedures for data preprocessing of GPR radargrams are presented. Raw data taken from GPR are affected by different noises and instability of equipment. The data in this form, are not suitable for the further analysis. They must undergo a set of transformations in order to obtain indispensable information.

1 Introduction

GPR (Ground Penetrating Radar) has been the widely used for almost twenty years in archeology, geology, civil engineering. Number of applications in which it is used is still growing. This article presents some aspects of surface penetrating radar applications based on electromagnetism science, geophysics, signal and image processing. GPR can in noninvasive way quickly determine subsurface structure. A series of reflection traces collected along a transect are usually generated from a subsurface boundary such as a stratigraphic boundary or some other physical discontinuity such as water table or a horizontal feature of archaeological interest. All sedimentary layers or objects in the ground have particular physical and chemical properties that affect the velocity of electromagnetic energy propagation (the most important of which are electrical conductivity and magnetic permeability). The highest amplitude radar reflections usually occur at an interface of two relatively thick layers that have greatly varying properties. The problem with GPR reflections and with their radargram is such that if the soil layers are composed of almost exactly the same material as detected ground, or have the same physical and chemical properties, there will be no variation in properties, and therefore little or no reflection will occur at their interface. An additional problem is that the various structures occurring in the earth can produce the same effect on radargram and GPR operators have a problem with proper interpretation of images. The compositions of many wavelets reflected from different objects and materials are recorded from many depths in the ground to produce a series of reflections generated at one location. The two-dimensional profiles built of different traces appear as black, white, and gray horizontal bands depending on the reflected signal strength (strong reflections generate distinct black bands while medial reflections produce gray bands). There can also be point source reflections that are generated from one distinct point feature in the subsurface (i.e. individual rocks, metal objects, pipes). They are visible in two-dimensional profiles as reflection hyperbolas. Radargram is largely

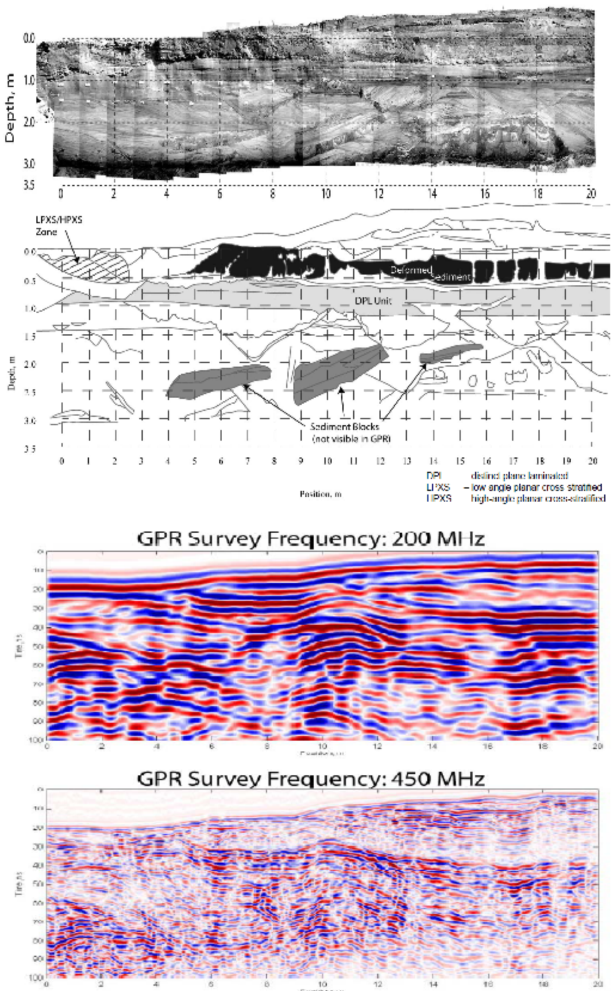

Fig. 1: Geological structure and corresponding reflection profile produced by GPR [4]

dependent on soil, surface topography, sediment mineralogy, clay content, ground moisture. All these elements make clear that the problem of interpreting the obtained 2-D profiles is not such an easy task and requires a lot of experience, knowledge and skills of the person interpreting the data. Examples of 2D GPR profiles of different geological structures are shown in the Fig. 1. The correct interpretation is conditioned by knowledge of the physical parameters of the underground environment.

Signal and image processing is a critical part of GPR

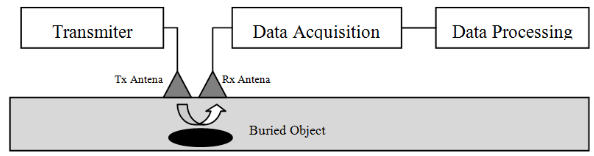

Fig. 2: GPR system

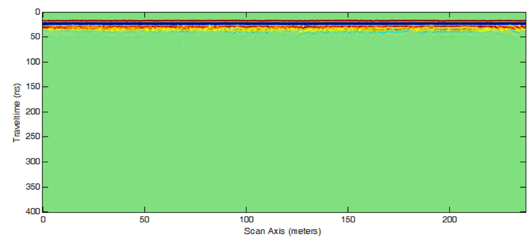

Fig. 3: GPR data (radargram)

data processing subsystem. The main objective of this part of software is to present data (image) at most readable form for interpreter. This part of software will be the basis for the next part of software necessary for classifying the returned signals on the basis of known templates or verifying procedures [1].

GPR sends EM waves in the ground and then collects backscattered echoes. GPR acquires signal traces (A-scans) moving along survey line. This raw data is then collected to form 2D GPR profile (B-scans). By moving antennas on two dimensional grid, we can get three-dimensional images (C-scans). Unfortunately the image created from this data is not in the form easy to understand because of scattering and diffraction so some procedures processing these data are necessary. The signal received by the GPR is at first an echo of the air-ground interface, than later in the time there appear reflections on target and clutter (background noise produced from subsurface reflections) in the subsurface. Reduction of clutter is a first procedure in the data preprocessing. Simple block - diagram of GPR system is presented in Fig. 2. and typical GPR data set in Fig. 3.

The data in this form, as seen in the Fig. 3 are not suitable for the analysis. They must undergo a set of transformations in order to obtain indispensable information.

2 Data Processing

Normal radar data processing consists of three main tasks [5]:

- selecting an adequate data processing flow
- choosing an appropriate set of parameters for each processing step
- observing final result of each processing step in radargram and correcting problems caused by incorrect parameter selection

A different sequence of processing steps can produce different final images so proper selection order of tasks has a great influence on the quality of image. It is a kind of art to find proper processing algorithms for the concrete problem of subsurface investigation.

2.1 Data Processing and Interpretation

Scientists working with GPR for various types of subsurfaces found that the principles of seismic stratigraphy could be applied to the interpretation of radar reflection profiles. Many of the methods used for seismic processing were adopted for GPR, especially those basic steps. However GPR waves are not seismic so there are some differences between them (i.e. form and nature of pulse GPR is more complex, attenuation and dispersion are more extreme). More advanced seismic-based processing algorithms cannot be used with GPR data. GPR data are much more influenced by clutter so procedures improving signal/noise coefficient are necessary.

2.2 Preprocessing phase - signal and image processing techniques

In this article we concentrate on simple pre-processing methods which can be applied first to each individual A-scans and later B-scans. As mentioned above GPR returns are usually of low resolution and have noisy content not suitable for direct interpretation. To solve this problem a set of different procedures should be applied to convert B-scan images to enhance resolution for better readability. This preprocessing operations are often performed by skilled operator. It require some amount of time and also is conditioned by human factors, such as accuracy and repeatability so automatic solution should be investigated. In this article we present only part of preprocessing procedures used for GPR radargrams. They can be found in Tab. 1 and it include such basic steps as Editing, Rubber-banding, Dewow, Time-zero correction and Filtering [6].

2.3 Signal processing

Methods for the preprocessing phase [2] [6]:

- Time-zero adjustment (Adjust Signal Position) - control of the vertical position of the surface reflection (the place in time where the radar pulse leaves the antenna, and enters the subsurface is considered as ”time zero”). Time-zero correction is necessary for adjusting all traces to common time-zero position before processing methods. This point is the time when the first break of air-wave or first negative peak of the trace is noticed.
- Radargram size reduction by discarding late-time arrivals reduces the size of the GPR data matrix by discarding the late arrivals.
- Per-trace subtraction (removal) of the DC component removes the DC component (arithmetic mean) from each trace of the GPR image.
- Wow elimination - dewow (or signal saturation correction) applies a running average filter to each trace to remove the initial DC signal component and low-frequency ”wow”. It is caused by signal saturation

Tab. 1: Basic description of the steps the GPR data processing

Editing	Removal and correction of bad/poor data and sorting of data files
Rubber-banding	Correction of data to ensure spatially uniform increments
Dewow	Correction of low-frequency and DC bias data
Time-zero correction	Correction of start time to match with surface position
Filtering	1D & 2D filtering to improve signal to noise ratio and visual quality
Deconvolution	Contraction of signal wavelets to "spikes" to enhance reflection event
Velocity analysis	Determining GPR wave velocities
Elevation correction	Correcting for the effect of topography
Migration	Corrections for the effect of survey geometry and spatial distribution
Depth conversion	Conversion of two-way travel times into depths
Display gains	Selection of appropriate gains for data display and interpretation
Image analysis	Using pattern or feature recognition tools
Attribute analysis	Attributing signal parameters or functions to identifiable features
Modelling analysis	Simulation of GPR responses

due to early wave arrivals, inductive coupling effects, and/or instrumentation dynamic range limitations (Fig. 4).

- Deamplification of raw DZT (GSSI) data (removal of DZT Header Gain) (not for MALA GPR).
- Data amplification by Standard Automatic Gain Control (Standard AGC), data amplification by Gaussian-tapered Automatic Gain Control (Gaussian-tapered AGC).
- Data amplification by the Inverse Power Decay applies gain function of the form

  $g(t) = scale * t^{power}$

  with power coefficient obtained during creating the best fitting power-law attenuation model.

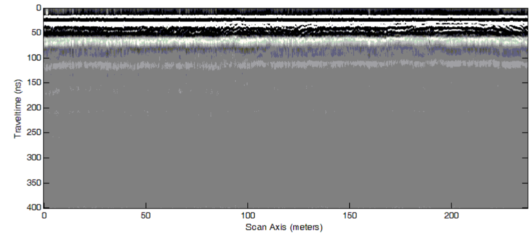

Fig. 4: Dewow of radargram from Fig. 3

- Data amplification by the Inverse Amplitude Decay applies an empirical gain function, which exactly compensates the mean, or median attenuation observed in a 2-D GPR radargram.
- Trace equalization creates the sum of the absolute values of all samples in a base trace and the same sum of absolute values is used for all traces by multiplying factor.
- Global Background or mean trace subtraction.

2.4 Filtering

Filters are applied to improve the quality of radargram by removing different types of noise, but they are also useful in extracting some interesting information from the recorded data. Simple filters are good for removing high-/low frequency noise. Sophisticated filters are necessary for specific problems (i.e. ringing) [6]. Filtering process should be applied carefully especially in complex heterogeneous environment, where scattering and clutter is more frequent than coherent reflection. The filtering should be conducted in the following order: vertical filtering then horizontal filtering. Time (temporal) filters alter the shape of single traces in the vertical direction to enhance or eliminate certain frequencies and features. Spatial filters work on a number of traces in distance. They are often combined to produce advanced 2D filters, which operate on time and space at the same time [2] [3].

2.4.1 1D temporal filters

- Simple mean - vertical filtering applies a running average filter vertically along each trace, with the primary purpose of reducing random and high frequency noise. Mean filtering is a simple, intuitive and easy to implement method of smoothing images, i.e. reducing the amount of intensity variation between one pixel and the next. It is often used to reduce noise in images. In general the mean filter acts as a lowpass frequency filter and, therefore, reduces the spatial intensity derivatives present in the image. With this kind of filter there are some problems: first - a single pixel with a very unrepresentative value can significantly affect the mean value of all the pixels in its neighbourhood, second when the filter neighbourhood straddles an edge, the filter will interpolate new values for pixels on the edge and so will blur that edge. This may be a problem if sharp edges are required in the output. Both of these problems are tackled by the median filter, which is often a better filter for reducing noise than the mean filter, but it takes longer to compute (Fig. 5).

- The median filter is normally used to reduce noise in an image, somewhat like the mean filter. However, it often does a better job than the mean filter of preserving useful detail in the image. Simple median (or alpha-mean trim) filtering applies a filter vertically along each trace, with the primary purpose of eliminating high frequency noise spikes. The median is a more robust average than the mean and so a single very unrepresentative pixel in a neighbourhood will not affect the median value significantly. Since the median value must actually be the value of one of the pixels in the neighbourhood, the median filter does not create new unrealistic pixel values when the filter straddles an edge. For this reason the median filter is much better at preserving sharp edges than the mean filter. In general, the median filter allows a great deal of high spatial frequency detail to pass while remaining very effective at removing noise on images [6]. One of the major problems with the median filter is that it is relatively expensive and complex to compute.

Frequency filters process an image in the frequency domain. The image is Fourier transformed, multiplied with the filter function and then re-transformed into the spatial domain. Attenuating high frequencies results in a smoother image in the spatial domain, attenuating low frequencies enhances the edges. All frequency filters can also be implemented in the spatial domain and, if there exists a simple kernel for the desired filter effect, it is computationally less expensive to perform the filtering in the spatial domain. Frequency filtering is more appropriate if no straightforward kernel can be found in the spatial domain, and may also be more efficient. Frequency filtering is based on the Fourier Transform. The operator usually takes an image and a filter function in the Fourier domain. This image is then multiplied with the filter function in a pixel-by-pixel fashion:

$$G(k,l) = F(k,l)H(k,l)$$

where $F(k,l)$ is the input image in the Fourier domain, $H(k,l)$ the filter function and $G(k,l)$ the filtered image. To obtain the resulting image in the spatial domain, $G(k,l)$ has to be re-transformed using the inverse Fourier Transform.

There are basically three different kinds of filters: low-pass, high-pass and band-pass filters.

- A low-pass filter attenuates high frequencies and retains low frequencies unchanged. It is used to re-

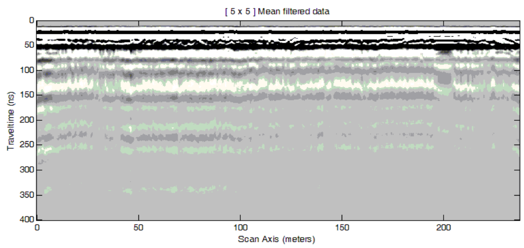

Fig. 5: Simple mean of radargram from Fig. 3

move high-frequency noise or "snow". The result in the spatial domain is equivalent to that of a smoothing filter; as the blocked high frequencies correspond to sharp intensity changes, i.e. to the fine-scale details and noise in the spatial domain image.

- A high-pass filter, on the other hand, removes the low frequency signal content in the temporal dimension. It is used to remove low frequency data and horizontal banding due to system noise. It yields edge enhancement or edge detection in the spatial domain, because edges contain many high frequencies. Areas of rather constant grey-level consist of mainly low frequencies and are therefore suppressed.
- A band-pass attenuates very low and very high frequencies, but retains a middle range band of frequencies. Band-pass filtering can be used to enhance edges (suppressing low frequencies) while reducing the noise at the same time (attenuating high frequencies).

2.4.2 Spatial Filters

Spatial filters alter the shape of adjacent traces in the horizontal (spatial) direction to enhance or eliminate certain frequencies and features in the section.

- Simple running average takes the mean of the number of traces. This filter is smoothing data horizontally (emphasizes flat-lying reflectors and at the same time suppressing dipping reflectors).
- Average subtraction - takes the mean of number of traces in window and subtracts it from each individual trace in sequence so it suppresses flat-lying reflectors.
- Background Subtraction (average subtraction) applies a running-average background subtraction to the data, subtracting the mean trace of a specific number of traces from each trace in the defined window, with the purpose of removing horizontal banding in profiles (due to system noise, electromagnetic interference, and surface reflections), thereby enhancing dipping events and blurring horizontal events.
- Horizontal (simple running average) filtering applies a running average filter horizontally, with the primary purpose of retaining flat-lying and low-dipping events while suppressing sharp dipping events and diffractions.
- Binomial (simple running average) filtering applies a binomial running average filter horizontally, with the primary purpose of retaining flat-lying and low-dipping events while suppressing sharp dipping events. It differs from the horizontal filter in that central traces in the running average window are weighted heavier than outside traces.
- Low-pass filtering removes the high frequency signal content in the temporal dimension. It is used to enhance flat-lying events and slowly-changing features, and suppress dipping events. It may also aid in removing horizontal banding due to low-frequency interference. The low-pass and high-pass spatial filters tend to produce the same results as the low-pass and high-pass temporal filters respectively.
- High-pass filtering removes the low frequency signal content in the temporal dimension. It is used to enhance localized features and suppress flat-lying and

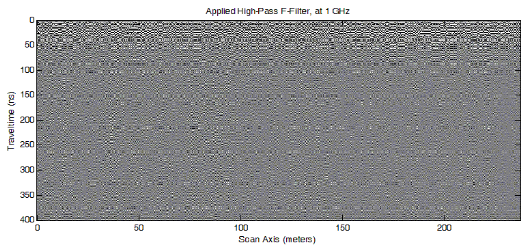

Fig. 6: High-pass filtering of radargram from Fig. 3

constant events (Fig. 6).

- Median (or alpha-mean trim) filtering applies a filter vertically along each trace, with the primary purpose of eliminating high frequency noise spikes and isolated faulty traces.
- Trace Difference filtering replaces each trace with the difference between itself and the previous trace, with the primary purpose of enhancing dipping (or rapidly changing) events and suppressing flat-lying (or relatively constant) events. It acts as a simplified high-pass filter [2].

Practically, some forms of filtering are always used but simplest methods are the most effective. In heterogeneous environment where different features for instance clutter and regions of low and high attenuation are present spatial filtering is not so helpful as on low-clutter data with strong air and ground responses.

3 Image Processing Techniques

In this part of the article some methods for enhancing radargram images are presented. The image processing methods in input have an image and on output create another image [7]. This methods supress or emphasis some details, reduce noise in image, make operation of smoothing, contrast stretching and edge enhancement. The common way to enhance images is changing the intensity values of pixels, i.e. by stretching - using special intensity mapping function for the whole image or special region of pixels.

3.1 Gray-scale Morphology

The most common binary image operations are called morphological operations, since they change the shape of the underlying binary objects [7].

- In this process the first level functions as dilation and erosion and the second level functions as opening and closing are used. By appropriate chain of this operation thinning, boundary extraction and filling can be implemented.
- Morphological Gradient is a procedure for highlighting level contours by calculating in the simplest form the difference between the highest and the lowest pixel intensity in a specified window.
- Feature extraction - orthogonal transformations, such as discrete cosine transform or discrete Fourier transform can be used.

3.2 Contrast Enhancement

- Morphological Contrast Enhancement can be implemented by using opening and closing operations realized on the original image. The opening and closing operations tend to leave large regions and smooth boundaries unaffected, while removing small objects or holes and smoothing boundaries. They are both derived from the fundamental operations of erosion and dilation. The basic effect of an opening is somewhat like erosion in that it tends to remove some of the foreground (bright) pixels from the edges of regions of foreground pixels. Closing is similar in some ways to dilation in that it tends to enlarge the boundaries of foreground regions in an image.
- Contrast stretching (often called normalization) is a simple image enhancement technique that attempts

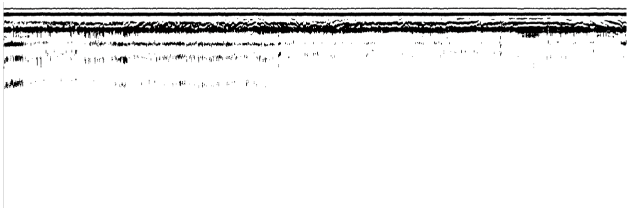

Fig. 7: Contrast enhancement of radargram from Fig. 3

to improve the contrast in an image by ”stretching” the range of intensity values. It differs from the more sophisticated histogram equalization in that it can only apply a linear scaling function to the image pixel values.

- Histogram Equalization - the main goal of this procedure [9] is to obtain the image with uniform histogram, so it is necessary to find an intensity mapping function f(I), such that the resulting histogram is flat. Sometimes it might be preferable to apply locally adaptive histogram equalization (Fig. 7).

4 Conclusion

In this paper we present some basic procedures for preprocessing GPR data sets. This methods will be the part of automatic approach for detection of geological features in GPR radargram. Interpretation of GPR data are invariably based on subjective analyses of reflection patterns. Such analyses are heavily depended on the interpreter’s experience. There is no one sequence of processing step for all GPR applications. The operator should be very critical and careful in choosing the appropriate processing scheme. What is very important, the same scheme should be used for all traces in localization. The recommendations by Cassidy [6] are helpful in deciding the order in which processing steps can be applied. At first GPR image should be properly denoised. In our opinion by using such simple methods, information about interesting and promising sections of radargram can be obtained.

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