Software tools for georadar data processing and visualization

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***Abstract*—This publication is an overview of software systems for digital signal processing of geo-radar (GPR) measurements with applications in ecology and protection of infrastructure of small earth embankment dams and river dikes. The duthors compare the capabilities of commercial software systems for processing and visualization of measurement results. The possibility of opportunities for using open source software in the primary data processing and visualization are discussed. Finally, an example is discussed of an application for visualization of geo-radar data with proprietary software tools and alternative open source free software like: Scilab, Octave and Seismic Unix.**

I. Introduction

The focus of this comparative study of the features supported by different software tools for data processing and visualization obtained by Ground Pennetration Radar (GPR) is on the investigatione of possible solutions for the development of an integrated methodology for non-destructive testing of small earth embankment dams and river beds. This study is part of a preliminary study on the project FFNNIPO 12 00368, funded by Bulgarian National Science Fund. [1] Problems associated with accidents caused by destruction of the earthworks due to improper maintenance and violation of their integrity have been frequent in Bulgaria over the past 10 years. This is reinforced by the fact that 98% of the national territory is vulnerable to earthquakes. This danger is combined with the high percentage of high-risk flood areas around the basins of major rivers and dams. Of all the dams constructed in Bulgaria over 2,000 are, with high walls, 171 with embankment walls and 26 with rockfill walls [2]. To figure should be added about 400 km strip bulk facilities along the river Danube and numerous dikes along the rivers in the country. Despite the timely efforts to renew and partial repayr of these facilities there are hundreds of embankment dams of uncertain ownership and de facto non in technical control, which circumstances combined with their years of service without repair often leads to disastrous consequences. Regardless of the facts and opinions of world experts in seismology on the relative stability of embankment dams to earthquakes [3], we suppose that these reports refer only to well-maintained facilities [4] which is not the case in Bulgaria. As for the maintenance of these facilities in good condition the majority of authors point the need for preventive monitoring (for dam design improvements) of their structure and integrity [5], [6], [7].

On the other hand water conservation, it's storing for agriculture and fisheries, as well as for the production of green energy in combination with the already built numerous solar parks, should be subject to deliberate and long-term state policy in the European Union [8]. In connection with the general guidelines and trends it can be concluded that more water tanks of different sizes will be needed to provide food, green energy, health, water transfer and transport in near future. Bulgaria is rich in water resources and should take advantage of its position in this regard the EC region, which could bring enormous economic benefits to the state and residents, as well to the improvement of it ecology and quality of life. The national policy in this regard should be applied gradually first directing to the restoration and protection of dams in Bulgaria, and later to the development of more small dams, which in combination with the solar photovoltaic green electricity will provide the energy backbone of the state. This means that a huge amount of research work into the integrity and strength of the existing dams and embankment dams should be carried out. The classical methods used for analysis by drilling and electrical impedance studies of embankment dams do not have the economic efficiency and are too slow for fast and qualitative analysis of the current situation. The aim of the project is to develop advanced methodology, using the experience of best practices in related EC projects, enabling the widespread use of non-destructive control of small earth embankment dams and river dikes with GPR systems in combination with standard drilling and electro impedance technology.

II. GPR Monitoring Methodology Basic Concept

The concept of the use of GPR with the monitoring of earth embankment dams may include a number of steps similar to those described below.

- Analysis of the structural characteristics of the site
- Finding information about possible problems
- Visual inspection of the site-photographs & GPS
- GPR measurement plan
- GPR measurement procedure
- Data archiving-online option
- Data visualization and processing
- Final evaluation by expert-sharing of the results
- *Appointment of further investigation by drilling

- *Final decision for repair or extension of the service
- *Computer modelling and simulation for the site

Characteristic of this method is the possibility of extensive subsequent computer processing of the results, precise GPR measurements and the possibility for fast and relatively inexpensive recheck adjustment. These options are not available when using the classical drilling procedures, however they can be used for the appointment of additional geological and engineering investigations [9]. Thus, there will be a decrease in the final price of the initial viewing of a large amount of earth embankment dams and levees, but also for large-scale application of the process resulting from the use of a cheaper and more easily transportable equipment. Moreover, the use of computer models will allow the combination of data derived from primary GPR measurements with data from a visual inspection, drilling, electrical impedance measurements and other classic methods. This will allow the development of more realistic 3D static models Fig. 1 of small dam structure, which eventually would help us to use computer simulations to analyze the stability of a facility under different conditions such as: earthquakes, water overflow, partially or totally destruction as a result of mechanical interference. The database could also be used for purposes of training geologists and engineers, as well as sharing of best practices among stakeholders.

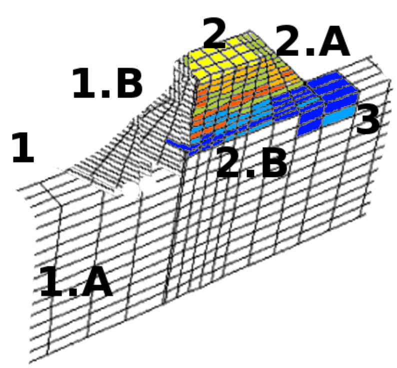

Fig. 1. 3D embankment dam static model

Such a model has several areas of vision: 1, 1.A, 1.B; 2, 2.A, 2.B and 3. Area 1(1.A, and 1.B) will be examined only in very small narrow dike walls, or provided that the water tank is empty. This requires similar control measurements to be carried out periodically from inside the levees when the reservoir is in emergency mode or maintenance. Other parts of the model can be reconstructed via vertial GPR penetration tests and side wall penetration. Area 3 can be tested in full scale. Due to the maximum precise penetration of several meters to several tens of meters 2.B area will be reconstructed with low resolution at high embankments. Following these limitations we believe that the use of GPR for investigation of earth embankment dams and river embankments is possible either at low water levels or limited, or as part of the drilling investigation of medium size dams. Notwithstanding these restrictions such a method would give us the necessary information for routine control of the strength of the earthworks. One possible solution for the investigation of water full dams is the use of underwater equipment [10].

In these measurements the test embankment is scanned vertically and on the slopes along its length. The records obtained in this manner give us the vertical and oblique structure of the dam. Upon completion of these tests, the data files should be archived and processed accordingly. Combining data from the GPS coordinates of each measurement and the results of different longitudinal scans through the use of specialized software we can reconstruct 3D digital model of the dam. Below is presented a short comperative review for possible options for the use of a software solution to similar problems in visualization and processing of the measurements made with GPR systems.

III. GPR OUTPUT DATA

GPR is used in geophysical research to image the subsurface. The method is based on the transmission of the short RF pulses in soil [11], [12] , as recorded reflections of individual pulses during their adoption allows us to create a picture of the nearby strata, underground infrastructure - pipes, cables, shafts, holes, large underground sites and groundwater, landslides, and more. The reflected part of the emitted electromagnetic wave (nanosecond pulses) is reflected from subsurface layers and objects and is detected back in to the receiving system of GPR - Fig. 2. Then the aquired data is converted to digital format and stored and visualized on the GPR monitor. Most often GPR units can show immediately the underground layers directly on the screen for the examiner to view them. The capabilities of most portable systems do not allow a serious post processing of the measurement data, which is why they should be transferred to a personal computer where using specialized software they can be visualized and processed.

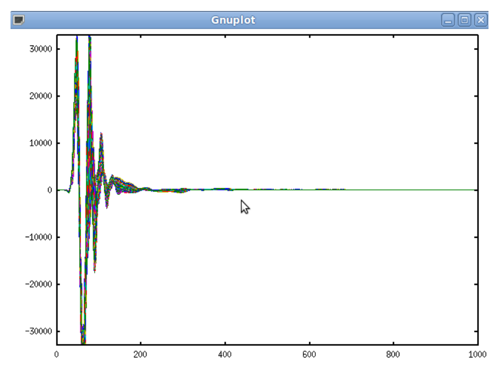

Fig. 2. Single pennetration GPR detected signal

In most cases, the examination of an object is performed in a predetermined term, and it is possible through the use of GPS the location of each puncture to be detected. So eventually by combining data from all individual measurements and cuts we can reconstruct a three-dimensional picture of the nearby subsoils. For the needs of the particular study portable georadar MALA XM3 was used with working frequensy of 250 MHz. The data was stored in the radar carrying information for each single measurement, arranged in the said vertical section. Basic parameters of these data are the number of significant points in the vertical direction and the number of individual measurements in each slice. Most data is stored in binary format files in consecutively recorded 16 bit values. These files have the extension ***.rd3**, as they were recorded, and an additional text file containing the specific parameters of a measuring setup with extendion ***.rad**. In a file with the extension ***.cor** may be recorded the geographical coordinates of all the conducted measurements. Different types of radars is possible to store additional information in the corresponding text files. Measurement data files can be read by any type of software tool and then processed and visualized as 2D images. Combining parallel 2D slices can create a corresponding 3D model of the entire underground scanned subsurface.

IV. GPR SIGNAL POST PROCESSING

The main issue in post processing of geo-radar images combining information from multiple penetrations is related to the fact that these data are not themselves two-dimensional images. Aggregation of individual penetrations in a 2D image allows us to obtain information about the individual strata, as well as for the existing underground infrastructure. Due to the specifics of the data aquisition process many images are reconstructed and superimposed and it is difficult for an untrained person to read itFig. 3. This causes serious difficulties in the processing of reconstructed images using classical techniques for digital processing. These techniques can be applied to a limited extent because the interpretation of the data is also very difficult due to the high dynamics of the resulting echoes. The highest level is the signal reflected from the nearest standing strata, as the data in depth have much lower amplitudes. The resulting images despite the possibility of further 2D and 3D reconstruction give us only integral evaluation of the located underground sites. Depending on the depth at which we wish to scan different operating frequencies are requred, leading to a limitation of the spatial resolution versus pennetration depth of the technique TABLE I. For the purpose of inspection with high resolution a frequencye range of up to 2.4 GHz can be used, which is usually done for the inspection of concrete coatings with reinforcements. In the context of the control of small dams it makes sense for planed regular inspections of internal and external concrete coatings, which can only be done at low water level.

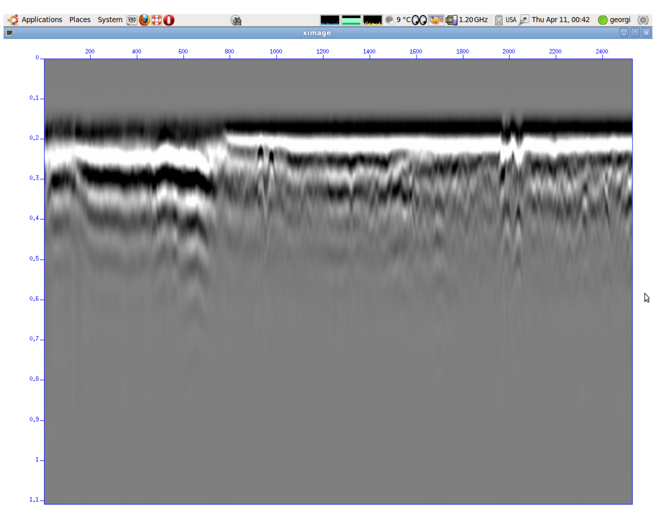

Fig. 3. 2D slice GPR reconstructed image, created by Seismic Unix http://timna.mines.edu/cwpcodes/

The GPR output file contains information from different

TABLE I. GPR FREQUENCY RANGE VERSUS RADIAL RESOLUTION AND PENNETRATION DEPTH

Frequency Range (MHz)	Radial Resolution (cm)	Penetration Depth (m)
25	100	50
50	50	40
100	25	25
200	10	8
250	5	6
500	3	2.5

penetrations that can be processed as a reconstructed 2D image or as a separate signals. In the latter case it is possible to achieve frequency correction of various harmonics, which can be removed in different noise penetration. It is possible to carry out low-frequency, high frequency, notch and band filtration, thus creating the conditions to visualize only thin layers, thick layers or small or larger objects. The user should be preconditioned on what tools should use when analyzing and inspecting objects using similar GPR slice images. Since the signals from the lower layers are much weaker, it is a common mistake not to consider them. Therefore it is important the person responsible for the inspection of objects to carry out a thorough and detailed inspection of all of the measurement results in full scale of the signal dynamic and frequency range. Below we describe the main capabilities for processing and reconstruction of 2D slices obtained by the GPR using different software tools.

V. GPR SOFTWARE

A. *MALA GPR GroundVision 2*

This is the basic software provided by the manufacturer of GPR system. With it can be visualized individual 2D slides, as they can be fixed with geographic coordinates and respectively the data can be exported for processing in other programs or stored and printed as black and white or colorized images. Since a radargram is a set of vertical signals with a resolution of 16 bits, the data can't be well visualized on standard monitors. There are problems related to the dynamics of black and white images by the inability of the monitors to display brightness deeper than 256 units. This problem is solved by the use of different color patterns to present data with a large dynamic range. Despite these possibilities the software has standard options to change image brightness and contrast. An interesting option of this simple software is the ability to apply different spectral masks on all single measurements thus making it possible to eliminate or enhance specific components of the reflected signal Fig. 4. This allows us to visualize only thin layers, only thick layers or remove large or small objects in a reconstructed 2D image. Through a combination of filters, it is possible to remove the specific waveforms, or to focus on only a certain geological structure in 2D image. This software is proprietary and no future adjustments and improvements can be done, it works on the operating system Windows.

B. *Genneral Purpose Software Tools*

Large amount of software for engineering research and training can be used for visualization and processing of radargrams. Most of these software is open source and can be used completely free for other engineering plans, calculations and simulations. The disadvantage of this kind of programs is that they work in interpreter mode and use reusable components for

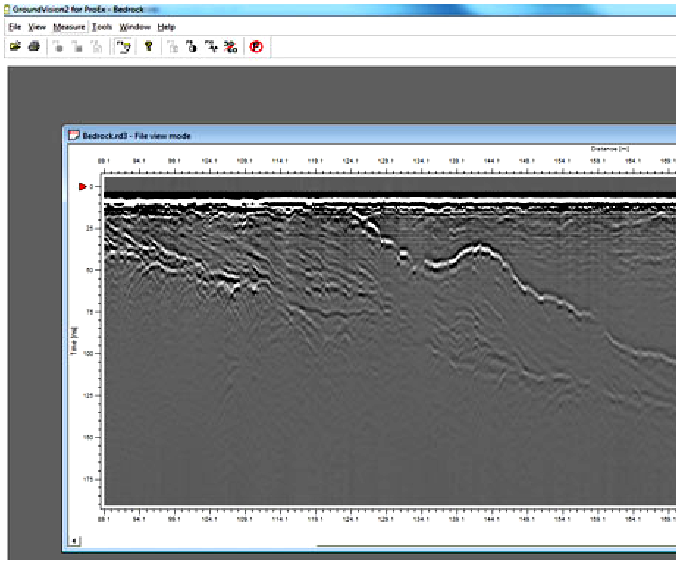

Fig. 4. GroundVision 2 - screenshot

drawing graphics and images, and can lead to serious delays in the processing and visualization [13] of large datasets in case of multi slice reconstruction of embankment dams. All that the programmer need to do is to open and read data files and fill 2D-16 bit integer matrix with values, attention should be taken in the case where the GPR uses big endian formatted data, the data bytes must be swapped before processing. These data form a 2D slice image and can be processed as a greyscale image, visualized as colorized immage procesed to brightness and contrast adjustment, or even to filter single pennetrations to remove or amplify exact spectral component.

- Matlab ®
- Mathematica ®
- Octave
- Scilab
- Python

C. Seismic Unix

This system integrates the experience of many experts in the field of seismology, part of which can be used for processing, and storage of data obtained from geo-radar, sonar or lidar. This project started in the early 1970. The Seismic Unix project is partially funded by the Society of Exploration Geophysicists (SEG), and by the Center for Wave Phenomena (CWP), Department of Geophysical Engineering, Colorado School of Mines. Past support for SU has included these groups, as well as the Gas Research Institute (GRI). [14] The system is Unix-based and written in the C language, thus making it very fast and efficient for large scale calculations. With this system it is possible to be carried out also simulation testing of a structure in terms of its earthquake resistance. The main drawback for ordinary users, is the fact that the environment does not have a graphical user interface. However, this makes it very flexible, different scripts and programs on Java, TCL/TK and Python and other high-level languages can be used to create a graphical interface or even Bash-scripts. Seismic Unix is decentralized open source system, making it very efficient and fast, which is an essential advantage over the monstrously slow closed applications. This system can be installed on Linux (in our case Ubunu) very easily please reffer to this linc http://www.seismicunix.com/w/Seismic_Unix_install_on_Ubuntu. The visualization system can be used through the implementation of short scripts or phasing writing commands referings to their different options [15].

```
# This command opens "*.rd3" file and reads sequence
# of 16 bit integer values, remaps data from short
# to float and store the output in to "a.f" file
recast < DAT_0013_A1.rd3 in=short out=float > a.f

# This command sets number of samples
# per each pennetration
suaddhead < a.f > a.su ns=992

# This command sets the total number
# of pennetrations per slide
sushw < a.su > aa.su key=dt a=samples*2942

# Visualize 2D image in BW format
suximage < aa.su perc=80 title="GPR slice" legend=1 &

# Remove temporary files to free disk space
rm a.f a.su
```

This code will produce the corresponding output greyscale image Fig 5. It is apparent the upper penetration section is well visible, but very low amplitude reflections from lower layers are not even visible at 256 halftone image.

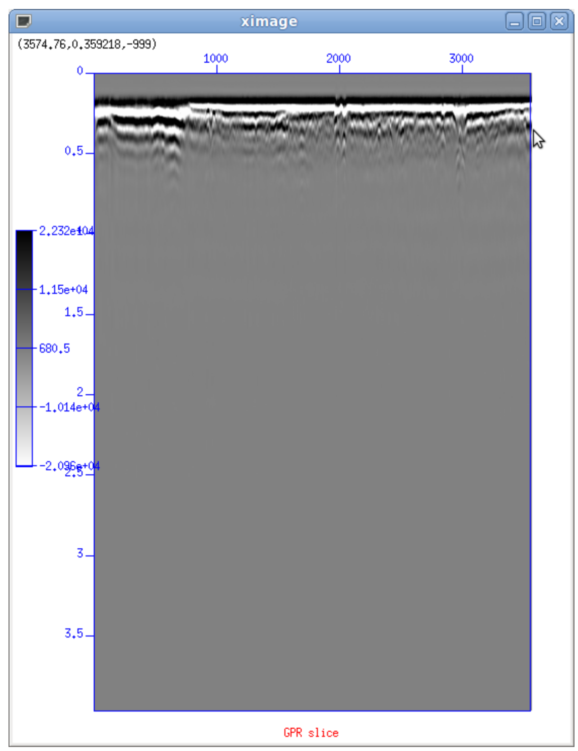

Fig. 5. SU standard BW slice visualization

Greyscale images that contain high dynamic range data are not always the easyer way to examine an entire image, because we need to make multiple review screens changing "perc=99, 98, 97, ..., 3, 2, 1" option see Fig. 7 and Fig. 6.

Our software allows you to color the halftone images so that the Leno can see large and small amplitudes radargram, this is done as follows Fig. 8:

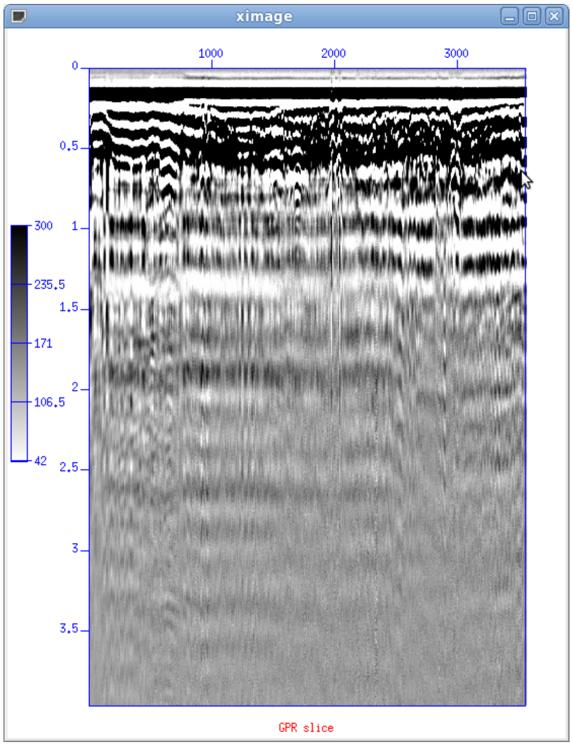

Fig. 6. SU BW slice visualization, perc=90

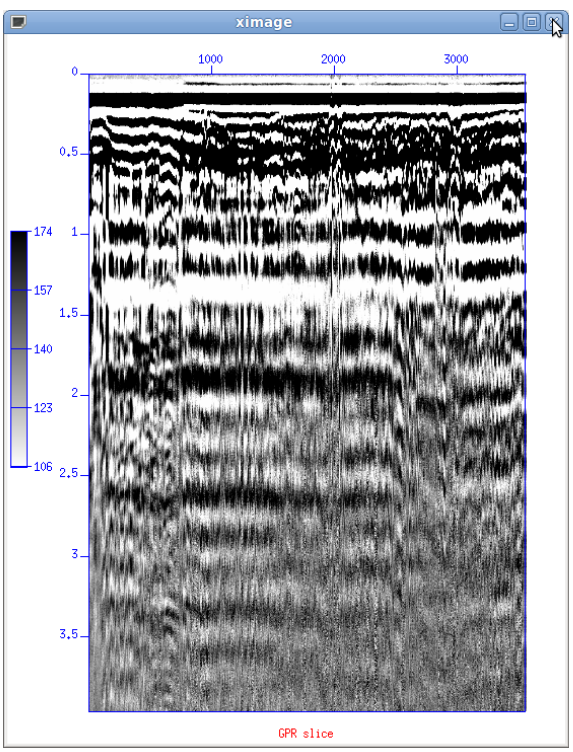

Fig. 7. SU BW slice visualization, perc=80

```
# Visualize "aa.ss" file data in HSV format
suximage < aa.su perc=80 title="GPR slice"
      legend=1 cmap=hsv2 &
```

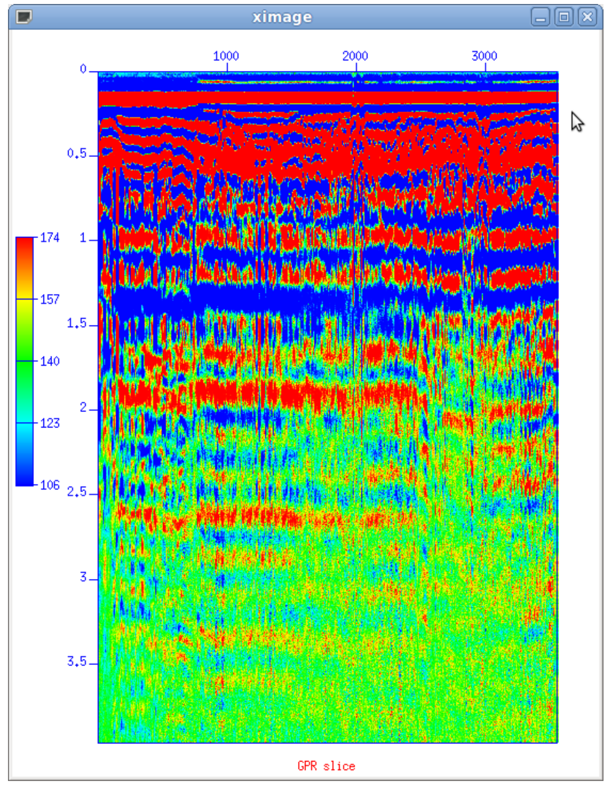

Fig. 8. SU HSV colorization slice visualization, hsv2, perc=80

In Seismic Unix there are several basic options that can perform image processing, such as statistical filtering: median, rms, maximum and others. Some of these features are obtained by the following command parameters:

```
sunormalize dt=1 norm=med < aa.su | suximage legend=1
   perc=80 cmap=hsv2 title="median" &

sunormalize dt=1 norm=med < aa.su | sunormalize dt=1
   norm=rms | suximage legend=1 perc=80 cmap=hsv2
   title="median & rms" &

sunormalize dt=1 norm=med < aa.su |
   sunormalize dt=1 norm=max | suximage legend=1
   perc=80 cmap=hsv2 title="median & max" &
```

VI. Conclusion

Our preliminary analysis on the possible use of additional software packages for processing and visualization of data from GPR shows that standard software applications can only be used for very basic analysis. There are many possibilities for the use of proprietary programs, however, they have two major drawbacks - high cost and inability to include new features. Such restrictions are unjustified in conducting scientific research, especially in the context of the particular study aimed to analyze and evaluate the stability of small embankment dams and river embankments. Possibilities are also discussed of using standard engineering computing packages like Matlab or Scilab. Their major advantage is ease

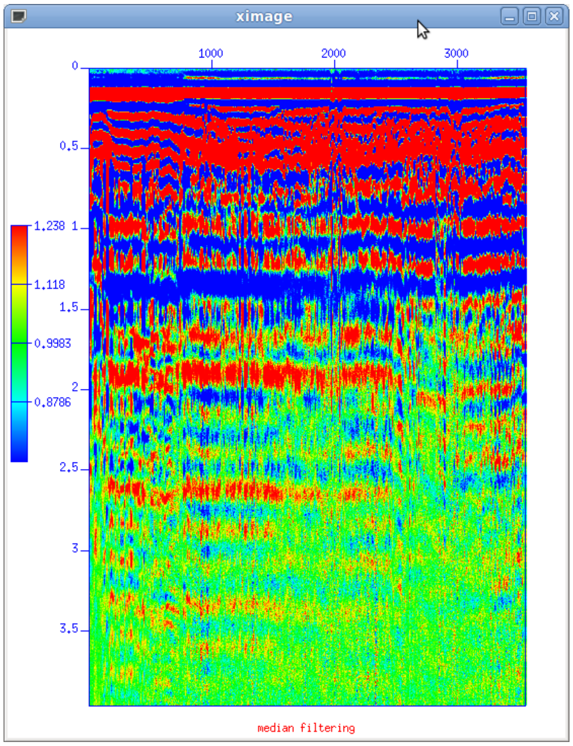

Fig. 9. SU HSV median filtering

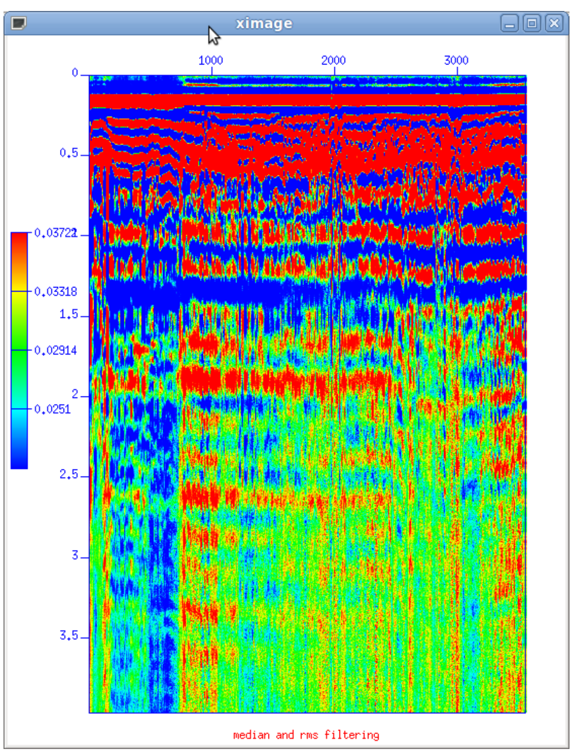

Fig. 10. SU HSV median and rms filtering

of adaptation in learning, while students may be explained in detail and illustrate how one or another algorithm is working, visualizing and filtering of signals and reconstructed images. The best software which showed perfect results and capabilities for processing and visualization GPR data is Seismic Unix. This software will be used for future analyses of GPR data with different pakages like OpenDX for 3D model visualization.

ACKNOWLEDGMENT

This work is supported by the project: Monitoring and prevention of environmental disasters by developing a methodology for georadar researches on rivers and dam embankment constructions, FFNNIPO 12 00368, funded by Bulgarian National Science Fund DFNI-M01/9/22.11.2012 - http://www.bulfund.com.

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