Data Analysis and Measurements for GPR and Roadway Instrumentation Systems

Electronic Communications Laboratory
Electrical & Computer Engineering Department

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University of Florida
Gainesville, FL

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Electronic Communications Laboratory
University of Florida
P.O. Box 140245
Gainesville, FL 32514-02145
(352) 392-1705
(352) 392-7169 [Fax]

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1.0 INTRODUCTION

The following sections outline the work completed by the Electronic Communications Laboratory (ECL) at the University of Florida for the Florida Department of Transportation (FDOT) project "Data Analysis and Measurements for GPR and Roadway Instrumentation System", Contract FM4037031B201. The tasks completed on this project were divided into four areas:

Test methods and procedures
Software improvements for roadway GPR
Training and presentations
Program management and reporting

This final report describes each task, outlines the work completed, and future work.

2.0 TEST METHODS AND PROCEDURES

2.1 Task Description

The UF/ECL made recommendations and interpreted results for GPR tests that were aimed at improving overall GPR measurement procedures, data collection, and potential accuracy of the GPR for roadway applications.

2.2 Work Completed

The work associated with this task was not specifically defined in order to allow for ECL engineers and FDOT personnel to direct the work to address issues that were affecting FDOT GPR work during the course of the project. Work that was done under this task is detailed in the progress reports and is summarized below.

2.2.1 Metal Plate and End Reflection File (Pulse Radar)

It has not been standard practice for the FDOT State Materials Office (SMO) GPR operators to obtain a new metal plate and end reflection file each time data is collected with the Pulse Radar GPR system. A new metal plate and end reflection file was collected at the beginning of this project and it was shown that it is necessary to take the metal plate and end reflection files before each data collection effort if maximum accuracy is to be obtained during processing of the GPR data. The metal plate file shows the most change for different times and configurations and it is very important that it be collected each time the antenna is attached to the van. The end reflection file does not change as rapidly but does change for different environmental conditions and over time (the aging of electronics). It is suggested that the end reflection file be collected each day that GPR data is collected.

2.2.2 Antenna Height Calibration (Pulse Radar)

A new antenna height calibration file was taken for the Pulse Radar system. During the collection of the antenna height calibration file, the gain of the radar was set incorrectly and the data was therefore not usable. Further testing showed that the previous curve used for calibrating the antenna height would be usable for future data collections.

2.2.3 GPR Filter Settings

Proper setting of the filters for collecting data with both the GSSI and Pulse Radar systems is very important. If filters are set too wide, too narrow, or severely asymmetrical, the data collected will be of little value for mathematical signal processing algorithms. The signal transmitted by the radar is a wide band signal that contains frequencies above and below the center frequency for which the antenna is usually named. Figure 1 shows a plot of the power versus frequency for the transmitted pulse from the Pulse radar system.

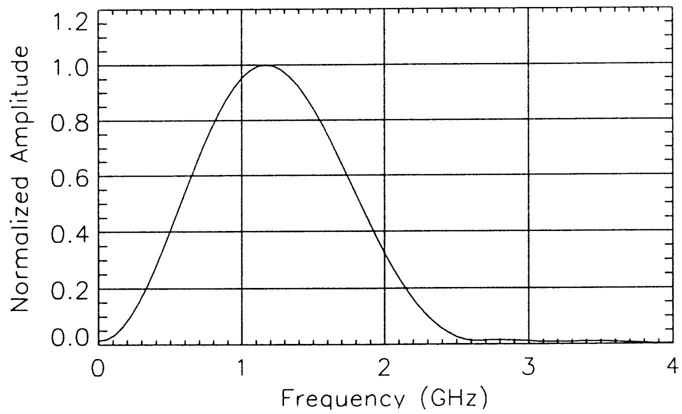

Figure 1. Metal Plate Frequency Response from Pulse Radar

The antenna is called a 1GHz antenna but the signal actually extends from a few hundred MHz to over 2GHz. Most of the power is centered if frequencies around the 1GHz center frequency and those frequencies are the most important to the signal processing algorithms. A good general rule of thumb for setting the high pass and low pass filters is to use Figure 2 or the values shown in Table 1.

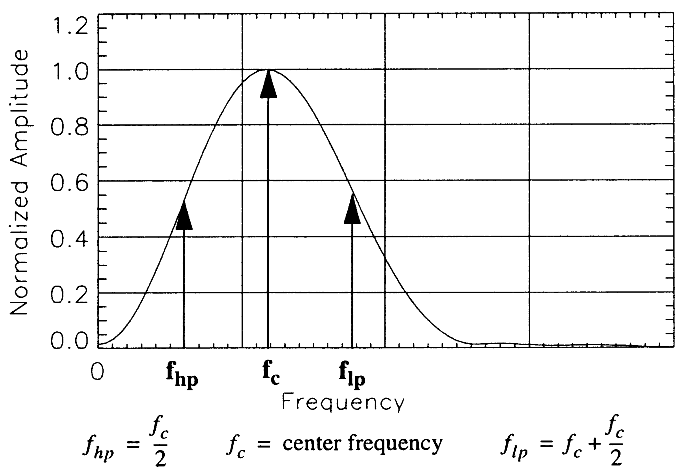

Figure 2. General Frequency Filter Setup for GPR

Table 1: General Frequency Filter Settings (MHz)

f_{hp}	f_c	f_{lp}
40	80	120
50	100	150
200	400	600
250	500	750
450	900	1350
500	1000	1500

There are many sources of interference when collecting GPR data. Interference can come from CB radios, cellular phones, TV stations, radio stations, and many others. The radar operator should be aware of these interference sources as it may be necessary to filter them out of the data.

2.2.4 FDOT GPR Test Pit Data (GSSI Radar)

Data collected from the new geophysical test pit at the FDOT SMO was delivered to the ECL for analysis. The objective was to locate buried objects with no prior knowledge of the test pit construction. The data was analyzed by the ECL and found to be seriously corrupted by amplitude clipping caused by improper gain settings during data collection. As part of this project, the ECL has worked with the FDOT SMO to identify methods of collecting GPR data with the GSSI system to mitigate the effects of clipping. The ECL requested that the data be re-collected and the FDOT SMO indicated that the data will not be recollected before the end of the project.

2.2.5 Clipping and Gain Settings

Clipping is the corruption of data due to attempts to represent quantities larger than the limits of a given numerical system. During collection of radar data, the analog radar signal that is returned from the ground is converted to a digital representation. For example, data collected from the GSSI is typically represented by a 16-bit binary integer. This allows representation over the range -32768 through 32767. Signal returns higher or lower than this range can not be represented. If the gains applied to the radar signal multiply the return such that its value is outside the numerical range, the analog-to-digital conversion process simply limits the value to -32768 or 32767. Once again, signal values above 32767 are all represented as 32767, and signal values below -32768 are all represented by -32768. So, signal returns of value 32780 and 62000 are represented as equivalent after conversion to digital by the radar even though one is nearly twice as large as the other. Information in the signal is, therefore, thrown away and can not be recovered. The mathematical integrity of the equations representing the physical electromagnetic phenomena utilized by the radar is also destroyed. Both of these problems limit the usefulness of clipped data for visualization or processing. For this reason, the gains applied to the return signals by the radar must be set such that signal returns do not exceed the numerical limits imposed by the analog-to-digital representation.

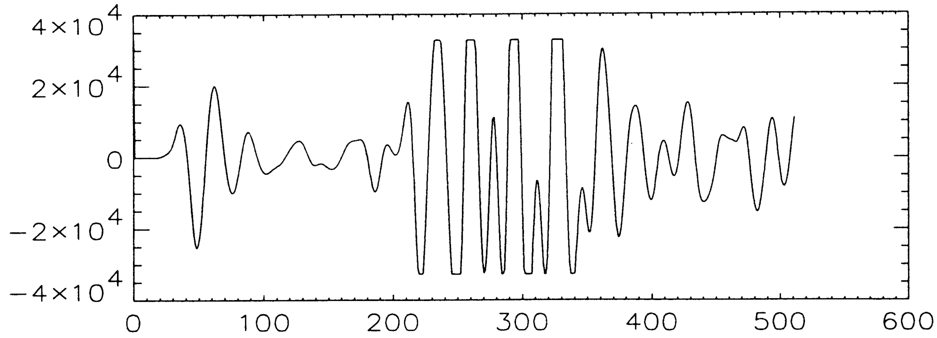

Figure 3. Example of Clipping Test Pit Data

FDOT data collections methods should be modified to avoid corrupting data. The gain function for the GSSI radar is typically set such that, when the antenna is placed on the surface with no targets below, the magnitude of the return shown on the display uses a significant part of the dynamic range (numerical range) of the radar. This presents a problem due to the fact that returns from actual targets are much higher and will then be amplified such that they exceed the numerical range of the radar and are clipped. To solve this problem, the gains must be set lower as described to FDOT personnel in previous progress reports.

2.2.6 DMI Re-calibration and Setup (Pulse Radar)

The FDOT SMO tested the DMI in the van and FDOT SMO GPR operators stated that the DMI was accurate. No records of the calibration were kept or are available. Setup of the DMI should be reviewed by FDOT SMO GPR operators to make certain that the setup is being done correctly for sampling in one foot, five foot, and other sampling intervals. The setup that has been described to ECL engineers does not correspond with written instructions from Pulse Radar Systems, the manufacturer of the GPR. The ECL is currently working with the FDOT SMO on another project (FDOT Research Project Work Order #6, Contract #BC354) and as a part of that project, ECL engineers are re-calibrating and testing the DMI and the Pulse Radar triggering system to make certain that the setup is performing correctly.

2.2.7 Automated GPR calibration methods

The FDOT SMO worked with roadway engineers within the FDOT to identify a site that could be used as a testing area for static, in-road, calibration targets for GPR. The plan was to place a metallic object (screen, plate, foil, etc.) inside the roadway at a known depth so that when the GPR van passes over the metallic target, a high amplitude return is recorded in the data that can be used to calibrate the measurements of the radar. The metallic object should be chosen so that it increases or maintains the structural integrity of the roadway. It was noted that if the metallic object is placed in a concrete roadway, it will be several months before testing can begin as the concrete must cure before the GPR will penetrate. One test was done in asphalt but the metal foil was placed too near the surface (~1 inch) and therefore interfered with the surface reflection. This test was done by the FDOT SMO without contacting the ECL. It was requested that any further tests be coordinated with the ECL so that efforts could be maximized.

Delays in locating a site pushed the testing of this type of calibration out of the scope of this project. It should be noted that discussions for this task were started before the project began in July of 1999 and have been brought to the attention of the FDOT SMO throughout the project.

2.2.8 DC OFFSET (PULSE RADAR)

ECL engineers have noted while working with the Pulse Radar system that is very easy to adjust the DC offset of the returned waveform. Software designed by the ECL does take DC offsets into account when processing GPR data but FDOT operators should note that changing this parameter can effect the effective dynamic range of the system if the DC offset is allowed become to large. The effect of adding a large DC offset will be realized as clipping in the GPR data.

2.2.9 ANTENNA SETUP (PULSE RADAR)

Returns from the air launched Pulse Radar system are very dependent on antenna orientation. The FDOT GPR van is equipped with a level and a ruler. FDOT GPR operators should take care to be certain that the GPR antenna is level on both axes and the proper height from the ground. Proper orientation of the antenna will allow for maximum energy of the transmitted pulse to be injected into the ground. Failure to set the antenna in the correct position will cause a decrease in energy penetrating the roadway surface and introduces additional errors into the computations of roadway layer interface depths and dielectric constants. Pulse Radar GPR signal processing algorithms are dependant on proper orientation of the antenna and the amplitudes of the metal plate file and subsequent returns from roadway interfaces. Improper antenna configurations (especially if the antenna is not level) will also allow for reflections from nearby vehicles to show up in the data with higher amplitudes than is normally observed.

2.2.10 GPR REPORTS

A part of this project was to make recommendations for the reporting and analysis of GPR data by the FDOT SMO. The ECL has requested from the FDOT SMO copies of previous reports of GPR data analysis that were completed by the FDOT SMO for the FDOT district engineers. ECL engineers were informed that such reports were not available. Without a clear understanding of previous work or examples of what results district engineers are looking for and what report format they are used to seeing, it is difficult to be specific when making recommendations for report formatting.

In general, good reports for GPR data contain the following:

- Exact physical data collection location
- Date
- Temperature
- Operators (during collection)
- Radar systems used
- Antenna frequencies used
- Names of data files
- Names of calibration files
- Reason for collection data (what are the goals of the data collection)
- Condition of pavements or geophysical surface (rough, painted, grass, roots, oil)
- Type of pavements or geophysical surface (concrete, asphalt, sand, clay)

Any known as-built information or coring information
Special circumstances (radio stations operating nearby, high water table / flooding, freezing temperatures, rain, unable to drive van at proper data collection speeds)
Data processing operator
GPR software used
Signal processing algorithms used
Results (detailed and summarized)

While all of the above information may not be necessary or important for the district or roadway engineer, it does provide a complete record of the data collection. Data could be kept in two separate reports (one for internal and one for external distribution) but this increases the complexity of the reporting. Utilizing a standard template for all GPR data analysis and collections would greatly improve the usefulness of the FDOT GPR assets. A standard report format also provides district engineers with a consistent format that they can become comfortable with and this should help to alleviate some of the mystery that is usually associated with data obtained with the GPR assets.

2.3 Future Work

Automated GPR calibration methods is an area of research that should be completed so that future GPR data collection efforts will have a standard method of calibrating the GPR prior to a data collection. This work would be beneficial to both network and project level data collections. Network level data collections could benefit the most from this effort as this would allow for calibrations of the GPR without coring. Coring is generally available at the project level but not at the network level. Work in this area must be coordinated with FDOT pavement design engineers so that any material integrated into the pavements for calibration, enhances or maintains the structural integrity of the roadway. The ECL has been working with the FDOT SMO in an effort to push this work forward but it does require the cooperation and some time commitment by the FDOT.

Consistent reporting methods by the FDOT GPR operators will provide a much needed historical archive of GPR data collection and processing as well as present the district engineers with a recognizable, familiar, and usable method of integrating GPR data into roadway rehabilitation and design. The ECL can provide much needed support in this area of work.

The ECL has many years of experience assisting and supporting in GPR data collection efforts for the Army and more recently for the FDOT. The ECL experience and guidance can be utilized by the FDOT for future GPR data collections. The ECL also has many more years experience in the processing of GPR and other radar data. The ECL would propose to continue assisting the FDOT in both methodologies and processing of GPR data.

3.0 SOFTWARE IMPROVEMENTS FOR ROADWAY GPR

3.1 TASK DESCRIPTION

An existing UF/ECL designed GPR software evaluation and analysis tool for roadway analysis was used as a start point for work on the task described in this section. Suggested improvements to the software were made by FDOT/SMO and UF/ECL and are summarized in the Final Report for Contract HPR Study 778, WPI 0510778 "Radar Signal Processing to Detect and Classify Subsurface Anomalies," July 1999. The following addressed most of the suggested improvements to the existing software. The software improvement tasks were:

- Retaining edited tracks
- Separate processing parameters
- Axes scaling and zooming
- Tagging GPR data
- Averaging depth data

3.1.1 RETAINING EDITED TRACKS

The previous GPR software tool allowed the operator to select and edit tracks for joining in order to form a continuous layer; the operator continues processing using the edited tracks. To evaluate pavement depths, the GPR processing breaks the edited track back into individual tracks. It is faster and more efficient for FDOT/SMO operators to keep the originally edited tracks, as assigned, for further processing. This software change enables the operator to retain the originally edited tracks for further processing.

3.1.2 SEPARATE PROCESSING PARAMETERS

The previous GPR software performs data analysis essentially in an off-line batch mode. One set of data analysis parameters is used for the entire file. This task: 1.) developed techniques to break up files for use of separate analysis parameters, and 2.) allowed concatenation of files after separate analyses have been run.

3.1.3 AXES SCALING AND ZOOMING

The previous GPR software tool plots data (time, depth, dielectric constant) on fixed scale axes. This effort developed software to zoom and scale axes. This feature allows for detailed examination of plots which is especially important for project level applications.

3.1.4 TAGGING GPR DATA

The previous GPR software tool tags the GPR data with the along-the-road distance obtained from the DMI. By noting a mile marker or other marker location relative to the DMI data, the location of subsurface features can be determined. FDOT districts have asked about the possibility of alternate location tagging techniques; these could include GPS or other separate position location systems. This task investigated and proposed alternate position location/data tagging techniques.

3.1.5 AVERAGING DEPTH DATA

The previous GPR software tool displays layer depths as dots across the screen, which represent the actual calculated depth at those points. For certain situations, the FDOT/SMO operators would prefer to average the data or perform a best fit. This is a departure from one of the basic design philosophies of the GPR software tool: that is, to maintain actual data with highest accuracy whenever possible. Nevertheless, it was possible to integrate an option into the software which allows the data to be averaged in ways that minimize the error. This effort studied, recommended, and implemented such an option. (Note: the operator can achieve similar results in the previous GPR tool by outputting the file for subsequent processing with ROADSEG).

3.2 Work Completed

The following is the summary of the software work completed for each part of this task.

3.2.1 Retaining Edited Tracks

A tool was added to the ECL GPR signal processing environment to enable the operator to retain the edited tracks for further processing. The software updates have been delivered to the FDOT SMO with verbal instructions. Written instructions and details of the use of this tool are contained in Progress Report 2.

3.2.2 Separate Processing Parameters

A tool was added to the ECL GPR signal processing environment that enables the operator to break up GPR data files into smaller sections. The smaller data file sections can then be processed by the operator with different processing parameters and concatenated back together into a single file. The software updates for this task have been delivered to the FDOT SMO with verbal instructions. Written instructions and details of the use of this tool are contained in Progress Report 2.

3.2.3 Axes Scaling and Zooming

A tool was added to the ECL GPR signal processing environment that enables the operator to enlarge GPR image data or GPR processed data for more detailed examination. Scaling plots of depth and dielectric constant has also been added to allow for different ranges of values to be plotted. The software updates for this task have been delivered to the FDOT SMO with verbal instructions. Written instructions on the use of this tool are contained in Progress Report 2.

3.2.4 Tagging GPR Data

A meeting with FDOT personnel was held in order to identify the requirements of the FDOT for location tagging with the FDOT GPR van. It was determined that current GPS technology is not capable of the accuracy (3 meters with averaging) or update rates (2Hz) required for the GPR data collection efforts of the FDOT unless differential mode GPS is employed. Differential GPS allows for an accuracy of less than 20cm with an update rate of 5Hz. Differential GPS is not practical for network-level collections as the range (1-5km) of the fixed unit is limited. Differential GPS could be implemented at the project level but would require an investment (up to $14,000 in equipment) by the FDOT in both the GPS and the integration of the data from the GPS with the two radar systems.

3.2.5 Averaging Depth Data

A tool was added to the ECL GPR signal processing environment that enables the operator to calculate the average depth to a tracked roadway layer interface. The software updates have been delivered to the FDOT SMO with verbal instructions. Written instructions for the use of this tool are contained in Progress Report 3.

3.3 FUTURE WORK

A new GPR software environment is currently being developed on another project (FDOT Research Project Work Order #6, Contract #BC354). This new GPR software environment builds on the work and research done on previous FDOT and Army contracts as well as the software described in this task. Many of the features of the new GPR software environment were taken directly from the software described in this report. The new software is also modular, allowing for the extension of the features currently integrated into the environment. FDOT GPR operators will most likely find that the new software is easier to use while providing many new features and most of the current features of the software described here.

The ECL would recommend that future software work be directed toward the new GPR software environment except for small enhancements. Support of a single software environment allows for more features to be incorporated into the software as well as reducing the duplication of efforts. It should be noted that the new GPR software environment supports both the Pulse Radar and GSSI radar systems so enhancements to this software benefit both radar systems and not just one as was done before the new software.

4.0 TRAINING AND PRESENTATIONS

4.1 Task Description

The UF/ECL was to present a one-day GPR roadway measurements and software training session to other FDOT district offices and to present a one-day GPR roadway measurements and software tool presentation for FDOT State Materials Office (SMO) personnel.

4.2 Work Completed

The FDOT SMO did not request, setup, or schedule a presentation for other FDOT district offices during the course of this project. UF/ECL engineers worked closely and met often with FDOT SMO personnel to ensure the transfer of methodologies, procedures, and software was completed. Hours assigned to this task were applied to the task "Test Methods and Procedures".

4.3 Future Work

No future work is planned or necessary for this task.

5.0 PROJECT MANAGEMENT AND REPORTING

5.1 Task Description

Project Management and reporting by the UF/ECL was required to ensure the completion of quality research and development. Quarterly project reports were delivered and oral briefings were completed.

5.2 Work Completed

Project reports were delivered to the FDOT and the local FDOT SMO that outlined the completed work. Because of the close proximity of the FDOT SMO, ECL engineers were able to interact with the FDOT personnel more often and with increased flexibility than the formal quarterly briefings that were envisioned for this task. ECL and FDOT personnel met together many times over the course of this project to discuss GPR performance, outline testing procedures, conduct software training, and interact on other GPR related topics. A formal meeting was conducted when the second progress report was delivered and another formal meeting will be conducted to present this final report.

5.3 Future Work

No future work is planned or necessary for this task.

CREDITS AND DISCLAIMER

Prepared in cooperation with the State of Florida Department of Transportation