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Automated Complex Resistivity Imaging of Rhizotrons (PSIP2E4D)

A user manual for automated processing of complex resistivity data

March 2022

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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Abstract

Complex resistivity (CR) is a remote subsurface sensing and imaging method that measures the frequency dependent electrochemical polarization across charged interfaces, like the interior plasma membrane and outer electrically resistive epidermis of plant roots (Kessouri et al., 2019). Ionic flux models of dynamic nutrient uptake rates at this interface can explain diurnal polarization trends observed in CR data, highlighting the sensitivity of time-lapse CR measurements to functional processes of root systems (Weigand and Kemna, 2019). Spatial resolution of CR is not adequate for resolving discrete root structure, but 2D and 3D images can be reconstructed that indicate root zones (Wu et al., 2017). CR technology is easily scalable, enabling hydrobiogeochemical investigation at both the lab and field scales that can provide data to support the understanding of dynamic earth system processes. A significant technical limitation exists, however, in processing the CR data using tomographic approaches to develop images of the complex conductivity distribution in time and space. To provide increased efficiency in collecting and processing this data, an automated complex resistivity tomography (CRT) processing software was developed.

Acknowledgments

The automated complex resistivity imaging software was funded by the US Department of Energy – Office of Science under the William R Wiley Environmental Molecular Sciences Laboratory project.

Acronyms and Abbreviations

CRT – Complex Resistivity Tomography

2D – Two-Dimensional

3D – Three Dimensional

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1.0 Introduction

The complex resistivity method in geophysics uses the transmission of electricity through a media as a proxy for multiple physical and hydrologic properties of the media. An extensive review of the method can be found in Binley and Slater (2020). Rhizosphere media typically consists of four components: soil, water, air, and biological material. Transmission of electricity through these media is dominated by water, as the presence of ions in the solution significantly increase the electrical conductivity of the fluid phase. Soil and biological materials, e.g. roots, are also expected to transmit electricity along surface conduction pathways

CR data collection is completed using a Portable Spectral Induced Polarization Unit and a Portable Spectral Induced Polarization Switch from Ontash and Ermac, Inc.

The intended audience for this user guide includes researchers and other practitioners familiar with geophysical methods and subsurface science. Guidance is given herein concerning how to set up automated processing of the complex electrical data. Users should also be familiar with E4D as processing of electrical data is performed using E4D software (e4d.pnnl.gov). To overcome technical issues that may arise, users should establish a working relationship with a geophysical subject matter expert familiar with these concepts prior to attempting to operate any equipment or collect any data as there are other steps to this workflow that cannot be automated.

All files and metadata for this project are located in the Bitbucket directory located at https://stash.pnnl.gov/projects/PSIP2E4D.

2.0 Walkthrough for Data Collection

The following procedure was developed to assist users in collecting and processing complex electrical data collected during plant growth experiments in rhizotron boxes.

1) **Consult a subject matter expert** in complex resistivity imaging during the experimental planning phase. It will be important to discuss the advantages and limitations of this technology during the planning phase as specific experimental designs may need to be considered to enable complex resistivity imaging. Discuss the technical needs with the SME and develop a plan for data collection that includes the following:

    a. Determine a name for your experiment that can be used to name data files in an iterative fashion using the date, e.g., *MyData_DDMMYY*, where DD indicates the two-digit day, MM indicates the two-digit month, and YY indicates the two-digit year. *MyData* will be referred to as a data file prefix throughout this manual.

    b. Complex resistivity equipment availability

        i. PNNL Assets WD85075 and WD85076 are available for EMSL users.

        ii. Electrodes for data acquisition are not tracked as assets but may exist.

    c. Data collection parameters

        i. Rhizotron dimensions

        ii. Number of electrodes and arrangement of complex resistivity array.

        iii. Over what frequency band will data be collected?

        iv. Time-lapse or static data collection? If time-lapse, how often will data collection be repeated?

    d. Electrode locations file generation

        i. The SME will need to create a *.txt* file with four columns that describes the location of all the electrodes. The columns should contain the electrode number, x-location, y-location, z-location, and control point flag (from mesh configuration file, see E4D user manual). Name this file *MyData_ElectrodeLocs.txt.* An example electrode location file is included in the Bitbucket repository as *MyData_ElectrodeLocs.txt*.

    e. Data collection sequence file generation

        i. The SME will need to create a *.csv* data collection sequence file that instructs the CR equipment on how to collect the data. A header containing the following information must precede any other data in the sequence file:

O&E PSIP Full Switch Sequence				
Version				
Name				
Date				
Time				
Comment				
End_Of_Header				
N	Stimulus+	Stimulus-	Sense+	Sense-

The cells to the right of the Version, Name, Date, Time, and Comment fields should be filled in appropriately, though the information is not used by the CR equipment. Note the Version field should correspond to the version of the acquisition software being used, which can be found on the data acquisition page of the CR equipment, e.g., v1.3.1g-2.

The rows below the final row of the header need to quantify the sequence number (N), the positive stimulus channel (Stimulus +), the negative stimulus channel (Stimulus -), the positive sense channel (Sense +), and the negative sense channel (Sense -). Name this file *MyData_Sequence.csv*. An example sequence file is included in the Bitbucket repository as *MyData_Sequence.csv*.

f. Mesh generation

   i. The SME will need to use E4D (e4d.pnnl.gov) to generate a mesh for the data processing step. See the E4D user manual on how to generate a mesh. The following files will need to be created using the data file prefix and tracked as they will need to be passed to the software during the automated imaging step:

   MyDataMesh.1.edge *MyDataMesh.1.ele* *MyDataMesh.1.face*
   MyDataMesh.1.neigh *MyDataMesh.1.node* *MyData.Mesh.1.trn*

   Example mesh files are included in the Bitbucket repository in the *Meshfile* folder.

g. Inverse options file generation

   i. The SME will need to create an inverse options file for E4D. See the E4D user manual for specifics. An example inverse options file is included in the Bitbucket repository as *MyData_Inv.opts*. Note that the AutoPSIP2E4D software replicates the inversion options file for both the real and imaginary conductivity inversions. The SME may need to tune these options if inversion results are not reasonable.

h. Output options file generation

   i. The SME will need to create an output options file for E4D. See the E4D user manual for specifics. An example output options file is included in the Bitbucket repository as *MyData_Out.opts*.

2) Prepare the rhizotron

    a. Construct the rhizotron from plastic or other electrically non-conductive materials when possible. The use of electrically conductive materials will impede the ability of the CR imaging to resolve the complex conductivity distribution in the sample.

    b. Ensure that the rhizotron is water-tight.

    c. Install electrodes in a robust way so that they are immobile. Cable glands or compression fittings are preferred. Special considerations may need to be taken for electrode design. See Breede et al., (2011) or Zimmerman et al., (2012) for specifics on electrode design in variably saturated soils.

3) Set up the CR equipment for data collection

    a. Connect the CR equipment to the electrodes in the rhizotron.

    b. Turn on the CR equipment and log in to the psip_user account using the password.

    c. Double click the '*EstablishSSH.pyc'* file on the desktop to establish a secure connection to high-performance computing resources that will perform the data analysis. If successful, a command prompt should show up indicating an SSH connection using a public key. The source python code *EstablishSSH.py* included in the Bitbucket repository.

    d. Open a command prompt and ensure that you are in the C:\Users\psip_user directory. Type AutoPSIP.pyc *MyData* where *MyData* is your data file prefix. You should see a message pop up in the command window every 10 seconds that says 'HH:MM:SS checking for new data files'. Now the CR equipment will automatically upload any CR data files present in C:\nginx-1.7.3\PSIP\logs that match your data file prefix to the high-performance computer once they are complete. The data files are also stored locally in C:\nginx-1.7.3\PSIP\logs\ToMax if you would like to save them. The source python code *AutoPSIP.py* is included in the Bitbucket repository.

4) Run a calibration test

    a. Prepare a volume of water to fill the rhizotron and measure the electrical conductivity with a benchtop conductivity meter. Record the measured electrical conductivity of the solution.

    b. Fill the rhizotron with the solution and collect data as if it were your sample.

    c. Work with the SME to determine if the real conductivity matches the expected value given the data from the conductivity meter. There should also be a minimal phase component to the data, given that no polarization mechanisms are present when only water is in the tank. Excessive polarization (>20 milliradians) may indicate that an electrode needs adjusted or replaced.

d. Use this opportunity to ensure that the AutoPSIP2E4D software is functioning properly. The calibration data you collected should be uploaded to the server and analyzed.

5) Rhizotron imaging

a. Collect data as you did with the calibration test, taking careful notes during the experiment.

b. Monitor the data as it is being analyzed in order to maintain agility if there are issues. You do not want to discover a problem with the data after your experiment has ended.

c. Maintain close contact with your SME and brief them periodically on the progress of the experiment. You may also want to hold regular data review meetings.

3.0 References

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