Advanced Utility Locating Technologies (R01B)

Jacob Sheehan
Senior Geophysicist
Olson Engineering

Phil Sirles
Principal Geophysicist
Olson Engineering
Introduction: Utility Bundle Overview

• **Product Overview**
  - 3D Utility Location Data Repository (R01A)
  - Identifying and Managing Utility Conflicts (R15B)
  - Utility Locating Technologies (R01B)

**SHRP2 – Strategic Highway Research Program**

**IAP – Implementation Assistance Program**

**Round 6: Proof of Concept** ($150K each agency)
California, Ohio, Arkansas, Oregon, Virginia

**Round 7: Lead Adopter** ($100K each agency)
Indiana, Montana
• **SHRP2 Solutions** – 63 products

• **Solution Development** – processes, software, testing procedures, and specifications

• **Field Testing** – refined in the field

• **Implementation** – 350 transportation projects; adopt as standard practice

• **SHRP2 Education Connection** – connecting next-generation professionals with next-generation innovations

350
SHRP2 projects nationwide
SHRP2 Implementation: Moving Us Forward

- **Funding Assistance**: $122 million
- **SHRP2 Solutions**: 63
- **Projects Implemented**: 350

Recipient Categories:
- DOT: 52 Recipients
- MPO/LOCAL: 29 Recipients
- UNIVERSITY: 10 Recipients
- FEDERAL/TRIBAL: 7 Recipients

Projects by Category:
- RENEWAL: 179
- CAPACITY: 95
- RELIABILITY: 65
- SAFETY: 11
SHRP2 Implementation: Moving Us Forward

145,831 Participants Engaged

5,713 Outreach Activities

6,155 Hours of Technical Assistance

- Training: 5,474
- Workshops: 152
- Peer Exchanges: 40
- Demos: 29
- Showcases: 18
Why Using Advanced 3D Utility Location & Delineation is Important
Utility Bundle (R01A/R01B/R15B)

Challenge: Locating and Managing Utilities
Solution: Three Products
Utility Locating Technologies (R01B)

MCGPR and TDEMI for 3D Utility Location
2D Utility Mapping

• Utility location services: X, Y
• Test holes at specified locations: Z (X, Y if surveyed)
• American Society of Civil Engineers ASCE 38-02

**Standard Guideline:**

- Quality Level D: Review of existing records: X, Y
- Quality Level C: Survey of visible appurtenances: X, Y
- **Quality Level B: Geophysical methods for underground utilities: X, Y**
- Quality Level A: Exposed utilities at specified locations: X, Y, Z
  - Test holes
  - Valves
  - Manholes
  - Vaults
  - Building basement walls
Traditional 2D Multi-Sensor/Technology Toolbox

Many types of systems:
- Radio-Frequency (RF)
- Electromagnetic Induction (EMI)
- Ground Penetrating Radar (GPR)
- Magnetometers (Mag)
- Acoustic sensors
- Inertial mapping inside pipes
- Use of sondes inside pipes

These are not replaced by advanced methods!
2 Technologies chosen for SHRP2 IAP to SUPPLEMENT the standard tool box for utility locating!

Advanced Geophysical Hardware

- Multi-Channel Ground Penetrating Radar (MCGPR)
- Time-Domain Electromagnetic Induction (TDEMI)

Advanced Software

- Software for processing, interpretation and visualization of MCGPR in 3D, and TDEMI data in 2D (plan-view)
Advanced Geophysical Methods: MCGPR & TDEMI

- Basic Theory
- Limitations
- Complications
- Variations
- Applications
- Why is works for utility mapping
- When it won’t work for utility mapping
- Requirements for effective use
- Final Products – What do you get out of the method?
Multi-Channel Ground Penetrating Radar
Basic GPR Theory

• Uses electromagnetic energy normally in the 10 MHz to 1500 MHz frequency range
  • Lower frequencies (*longer wavelengths*) image deeper but with lower resolution than higher frequencies (*shorter wavelengths*)

• Any change in the *dielectric constant* value (*next slide*) will generate a reflection.

• Reflected energy is measured at the GPR receiver
Basic GPR Concepts
Soil Suitability Map of the US

Suitability of GPR in Areas

<table>
<thead>
<tr>
<th>GPR Index</th>
<th>Suitability</th>
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<tbody>
<tr>
<td>1</td>
<td>Very High</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
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<td>4</td>
<td>Low</td>
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<tr>
<td>5</td>
<td>Very Low</td>
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- Water
- Large Water Body
- Not Digitized
- Urban Areas
- International Border
- State Line
- Interstate Highway
Basic Concepts
Types of GPR Antennas

Air-Horn

Adjustable Low Frequency (MLF-Multi-Low Frequency)

Note the lack of GPS (need)

Antenna Size

Frequency

Depth of Penetration

Resolution

Small = High = Shallow = High

Big = Low = Deep = Low

*Mapping rebar and PST’s

Mono static

Mono static*
Same transect – two different GPR frequency antennas

400 MHz Transect

200 MHz Transect
Frequency vs. Resolution of Anomalies

Same transect – three different frequency antennas

*Same time scales

Lower Frequency ‘sees’ Deeper
What Makes GPR Complex

• **Will a feature cause a reflection?**
  - Depends on:
    • Dielectric constant of feature
    • Dielectric constant of material feature is in or next to
    • Signal strength at feature (is your signal strong enough to go from surface, to feature, and back?). Depends on initial signal strength and absorption/attenuation of material between the surface and the feature of interest.

• **Data requires expert interpretation**
  - Is a reflection caused by a utility, rock, void?
  - Near surface or even surficial features will create “echoes” downward in time. Important to note the earliest time (or shallowest depth) that the feature is present
  - Interpretation is, to a large part, subjective. Two experts can come to different conclusions

• **Often GPR will simply not work due to geologic conditions**
  - It is very important to understand why and when this will be the case
  - Requires background research or knowledge of the site

• **Even single sensor and single frequency system generate large data sets.** Advanced systems generate huge data sets that require special software and organization to make the most of.
Example
Where GPR Does Not Work
External Noise Sources

- Radio Signals
- Police RADAR guns
- Cell Phones
- Hand Held Radios
- And more…
How to Understand Radargrams

• The results from GPR surveys are often complicated to understand

• The Y axis is often time, not depth
  • This is because the response as a function of time is what is actually measured
  • Can be converted to depth if a velocity is assumed

• Often responses from multiple features overlap
  • Responses from shallow features can cause echoes going down in time (or depth) that can complicate interpretations of deeper features

• Uneven terrain can cause the instrument to bounce, causing false anomalies
Utilities Detection and Mapping

- Real Time Detection
- Single Antenna Systems
- Detection and Mapping
- Multi-Channel Systems
- Mapping for Trencher
- Multi-Frequency Systems
- Advanced system for extensive 3D utilities mapping
- STREAM-EM MCGPR
Advanced Multi-channel GPR - MCGPR

IDS Stream-EM System

3D Radar System
GPS or Total Station

1x200 MHz DML array for detecting main pipes along the road (6 cm transversal sampling; VV polarization)

Stream X: the DML array can be extracted from the Stream-EM to be used in the Stream-X configuration for archeology or environment surveys.

4 dual frequency 200-600 MHz antennas (DCL array) for the detection of shallow and deep junctions (HH polarization)

MF Hi-Mod: the DCL array can be extracted from the Stream-EM to be used in the MF Hi-Mod configuration for mapping sidewalks and areas with difficult accessibility.

Modular composition: easily reassembled
GPR Results
Depth Slicing 3D Volume
3D Radar Theory Of Operation

Principle of Operation

3D-RADAR DX/DXG-Series Multi-Channel Air and Ground Coupled Antenna Arrays

- RTK Base Station (optional)
- UHF Data link
- RTK GPS antenna (optional)
- GeoScope Radar Unit
- Ethernet
- Operator PC

Inline direction, x

Cross-line direction, y

Depth, z (time, ns)
3D Radar Theory Of Operation
Step-frequency waveform
Airport Runway Inspection

Copenhagen Kastrup airport:
Area covered: 3 km x 60 m
Survey duration: 5 h 20 min

No closure necessary

Power cables – 1
Power cables – 2
Tunnel ceiling
3D Radar Theory Of Operation
3d-imaging

In-line profile

Horizontal slice

Cross profile
Another 3D RADAR Example

Bridge Deck Bottom

Support Girders
Time-Domain Electromagnetic Induction
TDEMI Applications

• TDEMI is very flexible and can be used for everything from metal detection to geology mapping.

• For Geology mapping, larger Tx and Rx loops are used, and transmitter turn-off is very controlled and measured. The important information is not just signal amplitude, but where the amplitude is in time after transmitter shut-off (which time gates).

• For metal mapping, smaller Tx and Rx loops are used, often with many turns in the wire.
Wrap-up ‘Other’ TDEMI Applications

- Is used on scales measured in inches and miles – mineral exploration
- Loops as large as a mile on side or as small as a centimeter
- Can be installed on carts, hand carried, laid out on the ground or be installed on helicopters or airplanes
When Does TDEMI Work Well for Utilities?

- When the target utility is metal (*ferrous & non-ferrous*)
- When utility is within the top 5-10 feet (*or so*)
- In any (*or at least most*) geologic settings
An Example Where GPR Does Not Work

• When the survey area has too much metallic items at the surface.
  - For example, TDEMI will not work along a guard rail, near cars or through reinforced concrete

• When utility is non-metallic, such as:
  - Fiber optic cables without tracer wires
  - PVC, clay or non-reinforced cement pipes
  - Utilities that are too deep

• When depth to the utility is required (TDEMI only maps the lateral location, not depth).
An Example Where GPR Does Not Work
TDEMI an GPR over the same site
TDEMI system used for the DOT demos: Geonics EM61-MK2

Specifications

MEASURED QUANTITIES
- Four time gates of secondary response in mV

EM SOURCE
- Air-cored coil, 1 x 0.5 m size

CURRENT WAVEFORM
- Unipolar rectangular current with 25% duty cycle

EM SENSORS
1. Main: Air-cored coil, 1 x 0.5 m in size, coincident with EM source
2. Focusing: Air-cored coil, 1 x 0.5 m in size, 30 cm above main coil

DYNAMIC RANGE
- 18 bits

OUTPUT MONITORS
- Color active matrix TFT-LCD 240x360 pixels, and audio tone

DATA STORAGE
- 512 MB internal disk; SD and CF slots, user accessible

DATA OUTPUT
- RS232 - serial port, Bluetooth

POWER SOURCE
- 12 V rechargeable battery for 4 h continuous operation

OPERATING TEMPERATURE
- -30°C to +60°C

OPERATING WEIGHTS & DIMENSIONS
- 41 kg trailer mode;
  - 100 x 50 x 5 cm (bottom),
  - 100 x 50 x 2 cm (top)
TDEMI Conceptual Cart Design (*for Demonstration)
TDEMI Actual Cart for Demo
TDEM setup used for all DOT Demos
IDS StreamEM in use at ORDOT and two CALTRANS Demos
3D RADAR system used at ODOT, VDOT and ARDOT
TDEM Example from Caltrans
Example from ORDOT
TDEM Example from ARDOT
TDEM and MCGPR can be good supplemental technologies for complex utility detection projects.
Both have limitations, which need to be understood before deployment.
The limitations are not the same – meaning that when one method won’t work, the other often can.
Some experience with the methods is required to collect, process and interpret the data.
Training on these two methods for advanced utility location could be provided for DOTs not participating in the SHRP2 program.

For more information about the SHRP2 program see:

https://www.fhwa.dot.gov/goshrp2/