Locating Buried Structures with Ground-penetrating Radar

1. Description of the device
    - A GPR is a device which uses radio wave reflection to measure the location of underground objects at close range.
    - Cross-section image produced
    - Different devices use different frequencies. Frequencies around 1000 MHz (microwave spectrum) are common for generic applications. (Between 200 MHz and 2000 MHz are used).
    - Higher frequencies give better resolution at the expense of a shorter range.
    - 1000 MHz good for shallow archaeological targets up to 1m deep. Resolution about 10 cm.
    - Although low frequencies give better range, objects close to surface may be missed.

2. ImRa
    - Antennas 800 MHz, 100 MHz, 1500 MHz (wavelength of about 40 cm to 20 cm in air.)
    - Portable, battery operated, can be operated in harsh conditions.
    - Easy to use, intuitive interface.
    - ImraLab application for processing measurements on PC.

[Photo of antenna in field measurement sledge.]

3. Formation of echos
    - Based on measuring the time between sent and received radio impulses.
    - Radio waves travel at the speed of light, back-and-forth travel time can be translated to distance.
    - Radio waves get reflected at points where the permittivity (denoted by epsilon) of the material changes.
    - Epsilon value NOT related to hydraulic conductivity or permeability used in hydrogeology, but to the electromagnetic properties of the soil.
    - Different soil types and materials have different epsilon values, and radar waves get reflected at their boundaries in the ground.
    - Electrically conductive materials such as water (especially salt water) and metal give very strong reflections.

4. Effect of soil type
    - The performance of the radar depends on the permittivity ('epsilon') of the measured material.
    - Different soil types have different epsilon values and attenuation characteristics.
    - Epsilon affects the speed at which the radio waves travel in the material. In practise this means changes to the radar range and resolution according to soil type.
    - The radar measures time, depth is an estimate based on the (known) epsilon value of the ground.
    - Finding the correct epsilon value is often difficult.
    - Epsilon may change due to rain, drying or freezing.
    - Epsilon not constant if various soil types present or ground water level in range.
    - Test measurements of a reflecting object buried at a known depth help determine the local epsilon value.
    - A higher epsilon value means slower travel, which in turn translates to shorter range but better resolution.
    - The soil attenuates the signal, which further limits range. Attenuation is somewhat independent of impulse travel speed (situations with poor resolution AND poor range are possible, but the converse not, unless better hardware is used).

[Graph of resolution and range, table of epsilon values.]

5. Soil type examples

- Different soil types have different permittivities, ranging generally from 1.0 for air to 10 for concrete to over 80 for fresh water, depending on temperature.
- A high permittivity means slow radio wave propagation and hence reduced range and increased resolution.
- For example, if a radar has a resolution of 30 cm and a nominal range of 3 m in air (epsilon 1.0), it will have a resolution of about 9,5 cm and a range of 1,9 m in concrete (epsilon 10.0). In wet clay (epsilon about 40) the values would be about 5 cm and 50 cm respectively.

6. Examples of good and bad conditions for measurement

- Dry, smooth sand is good measurement ground.
- Seawater will block all radar signals.
- The antenna should have close contact with the ground, rough terrain may make measuring impossible as the signal reflects from the surface without being passed into the ground.
- A worst-case scenario might be a wet clay base covered in rough blocky metal-containing waste, for example a building site with demolition waste.
- Snow or ice isn't bad for measurement. Frozen ground gives a much better range than wet ground, as ice epsilon is only around 2,5.

7. Post-processing

- After measuring, the radar images can be processed on a pc with the ImraLab application.
- The images can be filtered and viewed with different color palettes, compared to each other and composited into a 3d image.
- ImraLab is easy to use and intuitive.

8. Typical interference

- Raw images often contain a lot of interference and unwanted signals. Targets can even be entirely obscured.
- Typical sources of interference are:
    - Constant echo, caused by signal reflections within the radar electronics. Appears as an unchanging wavy pattern over the entire radar image.
    - Noise. All signals exhibit random noise, which can mask weak reflections. Noise may also originate from other radio equipment, particularly mobile phones. Random noise appears as a grainy pattern over the image, mobile phone noise causes sharp spikes.
    - Depth drift caused by heating of the radar electronics. The radar electronics compensate against thermal drifting, but quick changes in temperature, for example due to sunshine on a very hot day, can affect the depth setting of the radar. Not disturbing by itself, but affects constant echo removal.
    - Unwanted reflections. Metallic objects like cars can show in the image even when not in the direction of the antenna. Appearance depends on scale and distance, often look like "real" reflections.

9. Interference samples.

- Constant echo, wavy pattern overlaid on the image
- Noise makes the image grainy
- Unwanted reflection: A garage door causes a reflection which looks like a soil-type interface. The antenna closes in to the door from right to left, so the reflection is inclined upwards.

- Depth drift causes a vertical shearing in the image, so the constant echo is not ”constant” over a vertical line.

10. Filter examples

11. Filtered sequence

12. Composite measurements
    - Combined from many closely spaced parallel or criss-crossing measurements.
    - Produce a three-dimensional view which reveals the continuous shape of structures, ”plan view”.
    - Even noisy measurements give good results. Reflections are reinforced, noise is not.

[Photo of field with measurement lines marked with string.]

13. Slice view in ImraLab
    - Each slice corresponds to one radar image.
    - The slices are arranged automatically. Their position can be fine-tuned manually.

[Top view rendering of the measurement of the field in the earlier photo.]

14. Criss-crossing slices, preview rendering
    - Individual slices arranged in a criss-cross pattern. Preview rendering in ImraLab.

15. Composite example
    - A measurement where single slices are largely uninterpretable indicates a clear structure when multiple slices are composited.
    - Strongly attenuating soil with lots of cluttering natural stones makes it difficult to distinguish important reflections from single slices.
    - The ring shaped reflections seen in the top-view rendering of the three-dimensional map probably originate from a circular limestone wall underground.

[Photo of partially excavated grave site (tumulus).]

16. Composite example
    - A multi-slice measurement of a field. (Viewed from above).
    - Dark areas represent strong reflections.
    - A lot of the reflections are clutter from natural stones.
    - The soil had a high attenuation, causing poor visibility.
    - The large, more uniform areas to the lower right may be buried stone walls.

17. Contact information.
    - For more information, you may contact our company or view the website
    - These slides can be downloaded from the website of the Finnish institute in Athens.