Use of GPR for monitoring and assessment of material properties in archaeological surveys

Fabio Tosti

School of Computing and Engineering, University of West London

September 28, 2016
The mission of Archaeology

“[..] Driven by a huge desire to see the world, I have consecrated and devoted all of myself, both to complete the investigation of what has long been the main object of my interest, i.e. to find the vestiges of antiquity all over the world, both to be able to entrust into writings those vestiges falling into disrepair for the long work of time ravages, because of human indifference [..]”

Ciriaco d’Ancona, 1391-1453/55

- To find “the past” → Detection/Assessment
- To protect the “discovered past” from the threat of the “present” → Monitoring
The threats (Natural factors)

Natural disasters (earthquakes, volcanism, hydro-geological events)

Coastal-erosive events

Water erosion

Climatic factors

Biological factors
The threats (Anthropic factors)

**Complex environments**

Pollution (air, water)
The main challenge is to go a step forward..

Ancient Age
Destructive archaeology

Middle Age
Minor-destructive archaeology

New Age
? 

- COST Action TU1208
  “Civil Engineering Applications of Ground Penetrating Radar”
The main challenge is to go a step forward..

Ancient Age
- Destructive archaeology

Middle Age
- Minor-destructive archaeology

New Age
- Non-destructive archaeology

..tackling the challenge!
Ground Penetrating Radar in archaeology

- non-destructive
- low cost
- easy to handle and rapid
- significant
- reliable

... but several issues ...

what can be expected? What can be done? how to extract practical information from GPR surveys?

How does GPR work?
Basics of the system
Ground Penetrating Radar in Archaeology
COST Action TU1208
“Civil Engineering Applications of Ground Penetrating Radar”

Key parameters

GPR characteristics (frequency, transmitted power)

Target characteristics (shape, EM properties)

Host material characteristics (EM properties)
Key parameters

GPR characteristics (frequency, transmitted power)

Target characteristics (shape, EM properties)

Host material characteristics, usually soil (EM properties)

EM properties of materials are crucial for effective and reliable target detection!
Two EM properties of importance for GPR

**Electrical conductivity \( \sigma \) (inverse of resistivity)**

- \( \sigma \) is a measure of a material’s ability to carry an electric current
- The value is primarily controlled by water content and/or clay content
- Higher conductivity makes radar signal penetration difficult

**Relative dielectric permittivity \( \varepsilon \) (Dielectric constant)**

- Measures the capacity of a material to store charge when an electric field is applied
- The value ranges from 1 to 81 (1 = air, 81 = water); the value (for soils) is mainly controlled by water content
- Differences in dielectric properties between two adjacent materials through which the radar wave propagates will cause reflection of some of the radar energy back to the surface
- The strength of reflections is controlled by the contrast in the dielectric constants of the two adjacent materials.
Investigation of soil EM properties (variable physical conditions)
Investigation of material EM properties - Roma Tre University, Italy (2010 – 2011)

**Survey protocols**

- **Mixing protocol**
  - Total
  - Comparison: % Total weight vs. % Sampled weight
  - Definition of the minimum content of clay to ensure the homogeneity of the mixture

- **Compaction protocol**
  - Proctor Test
  - Vibrating table
  - Comparison: $\gamma_d = \frac{m_d}{V}$
  - Definition of the vibration time of soil samples when using a vibrating table

- **Radar signal detection protocol**
  - Impact analysis of relevant factors on signal noise
Investigation of material EM properties - Roma Tre University, Italy (2010 – 2011)

- **GPR device**
  - GPR TX/RX 600-1600 MHz

- **Main equipment**
  - Test box
  - Mixer
  - Vibrating table
  - Atterberg limits

- **Soil material**
  - M. Magliana (0-5 mm)
  - Clay (Montmorillonite)

- **17 tests in dry conditions**
  - Range of clay content surveyed (0 - 30% clay)
  - Survey steps (2% clay)
Investigation of material EM properties – *TUDelft, The Netherlands (October – November 2012)*

- **GPR devices**
  - GPR TX/RX 500 MHz
  - VNA Ultra wide band

- **Main equipment**
  - Test box
  - Setting
  - Gas pycnometer
  - Mixer

- **Soil materials**
  - Gravel (4-8 mm)
  - Sand (1-2 mm)
  - Sand (0.125-0.250 mm)
  - Clay (Bentonite)

- **54 tests in dry conditions**
  - Range of clay content surveyed (0-25% clay)
  - Survey steps (2%; 5% clay)
Investigation of material EM properties - Roma Tre University, Italy (2010 – 2011)

GPR device
- GPR TX/RX 600-1600 MHz

Main equipment
- Test box
- Mixer
- Vibrating table
- Oven

Soil material
- M. Magliana (0-5 mm)

23 tests in wet conditions
- Three types of soil mixtures (5%; 10%; 15% clay)
- Survey steps (2% water)
Ground Penetrating Radar in Archaeology
COST Action TU1208
“Civil Engineering Applications of Ground Penetrating Radar”

Investigation of material EM properties – *TUDelft, The Netherlands (October – November 2012)*

- **GPR devices**
  - GPR TX/RX 500 MHz
  - VNA Ultra wide band

- **Main equipment**
  - Test box
  - Setting
  - Gas pycnometer
  - Mixer

- **Soil materials**
  - Gravel (4-8 mm)
  - Sand (1-2 mm)
  - Sand (0.125-0.250 mm)

- **104 tests in wet conditions**
  - Two mixtures per soil type surveyed (0%; 15% clay)
  - Survey steps (2%; 5% water)
Investigation of material EM properties – *Università degli Studi di Milano, Italy* (2012)

**Tools and equipment**

- Georadar IDS RIS 99
  1. Signal acquisition unit
  2. Signal generation unit
  3. Multi-Frequency ground-coupled antennas (Tx-Rx 600-1600 MHz)
  4. Wheel encoder

- Capacitance probe Water Scout SM 100
  - Range: 0% VWC to saturation
  - Resolution: 0.1% VWC
  - Sensing Area: 60 mm x 20 mm

**Experimental layout**

- Time Domain Reflectometer
  - Range span: 10 m to 3000 m
  - Resolution: 1% range span

- Geoelectrical tomography
  - Two electrodes array

- Test site 20m x 20m (Useful area 16m x 16m)
Investigation of material EM properties – *Università degli Studi di Milano, Italy* (2012)

- Intermediate-scale VWC comparisons:

VWCs from GPR ‘reflectivity method’ vs VWCs spatial distribution from ‘Scattering method’

- The comparison between the two maps shows a good agreement with the theoretical expectations

**Main Statistics**

- Field-average VWC: 
  \[ \theta_{f\text{avg GPR}} = 0.351 \text{ m}^3\text{ m}^{-3} \]

- Field VWC standard deviation: 
  \[ \theta_{f\text{std GPR}} = 0.0304 \text{ m}^3\text{ m}^{-3} \]
Intermediate-scale VWC comparisons:

VWCs from GPR ‘reflectivity method’ vs VWCs spatial distribution from ‘Scattering method’

- The comparison between the two maps shows a good agreement with the theoretical expectations.

- In that respect, some clear matches can be found:
  - parallel to the y axis throughout the whole length of the area (e.g., yellow shape: high moisture contents and low frequency peaks)
  - in the middle-western edge and in the south-western corner of the maps
  - in the south-eastern corner of the figures (e.g., grey dashed shapes: low moisture contents and high frequency peaks)

Water content – Test site

Main Statistics
- Field-average VWC: $\bar{\theta}_f^\text{GPR} = 0.351 \text{ m}^3\text{m}^{-3}$
- Field VWC standard deviation: $\theta_f^\text{std GPR} = 0.0304 \text{ m}^3\text{m}^{-3}$
Conclusions

- **The new challenge for archaeologists is to tend towards a non-destructive and self-consistent approach to increase target detectability and lower excavations.**

- **To retrieve reliable info on the target, It is essential to have an a-priori comprehensive understanding of the EM properties of soil, under variable physical conditions.**

- **Laboratory to full-scale investigations are suggested in order to achieve maximum reliability from (hosting) material characterisation.**
Thank you for your time and attention!