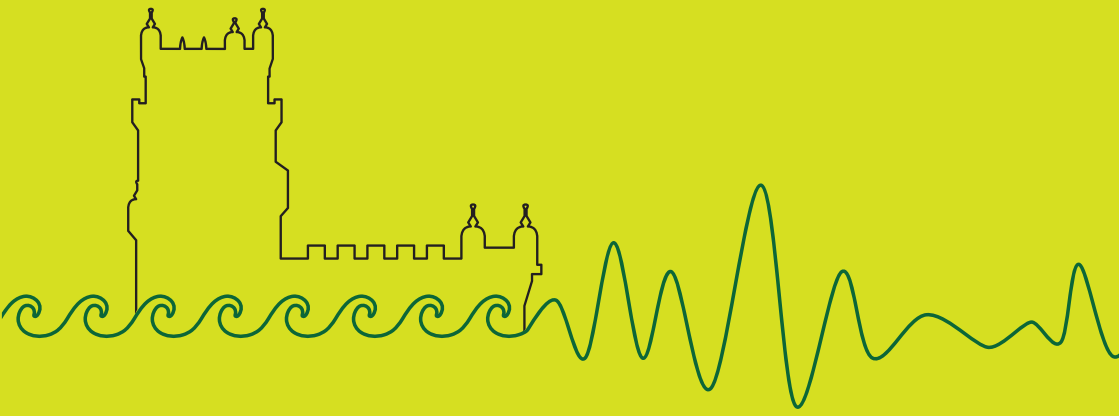
LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL



12th International Workshop on Advanced Ground Penetrating Radar

Lisbon, 5th to 7th of July, 2023

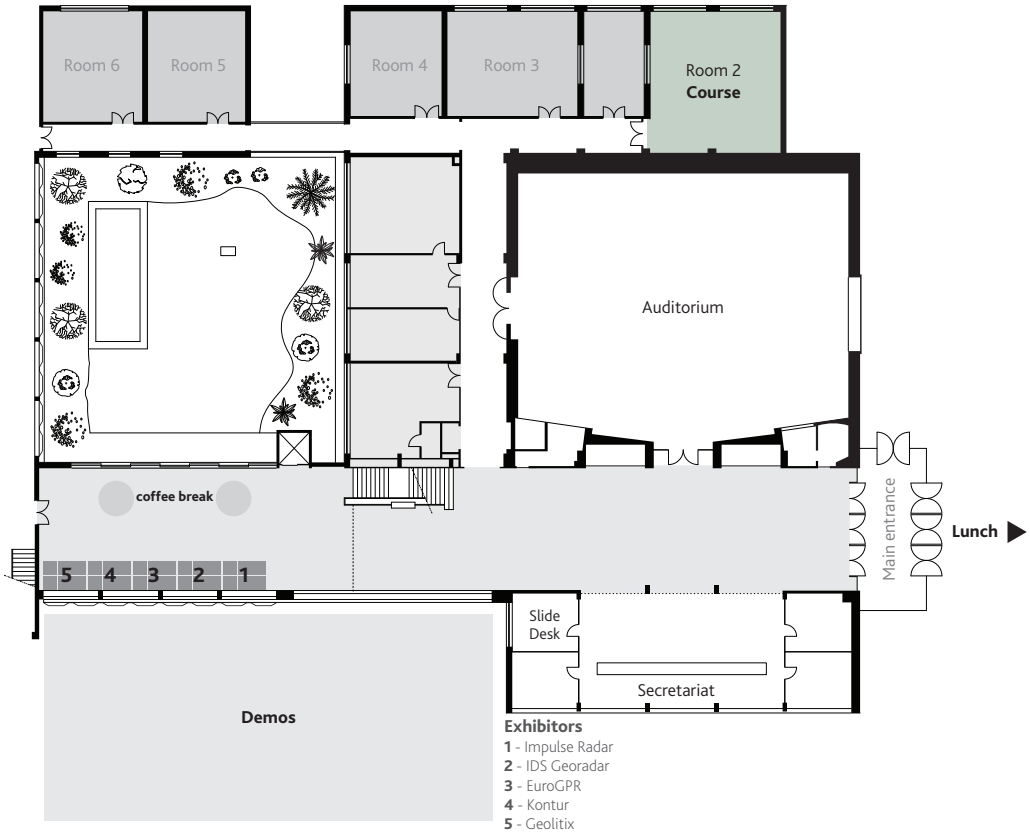
Programme

	July, 5th	July, 6th	July, 7th
9:00	**Registration***	Engineering and Geotechnical applications	Forward modelling
9:30	**Course** From Ground to Cloud – The Future of GPR Processing		
9:45			Security applications
10:00			
10:15		**Keynote Lecture** Andreas Loizos	**Keynote Lecture** Sébastien Lambot
10:30			
10:45	Coffee break	Coffee break	Coffee break
11:15	**Course** From Ground to Cloud – The Future of GPR Processing	Engineering and Geotechnical applications	Geological and environmental applications
11:30			
11:45			
12:00			
12:15			
12:30	Lunch	Lunch	Lunch
14:00	Opening ceremony	Posters session	Geological and environmental applications
14:15			
14:30		Demos session (IDS Georadar & Impulse Radar)	
14:45			
15:00	Novel developments in GPR systems and antennas		Archaeology and cultural heritage
15:15			
15:30		Proposals for IWAGPR 2025	Coffee break and Porto wine
15:45			
16:00	Coffee break	Coffee break	
16:30	EuroGPR Association	Engineering and Geotechnical applications	Best student paper award & closing ceremony
16:45	Advanced data and image processing algorithms		
17:00			
17:15			
17:30			
17:45			
18:00	Cocktail		
19:00		Dinner	

*** Registration**

July, 5th 9:00 to 12:30 - 14:00 to 16:30

July, 6th - 7th 9:00 to 11:15



Dinner directions

Gold sponsor

Turismo de Lisboa

Silver sponsor

impulse RADAR

IDS GeoRadar

EUROPEAN GPR ASSOCIATION

Bronze sponsor

Geolitix

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Maria João Coelho, LNEC, Portugal

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Vega Pérez-Gracia - Polytechnic University of Catalonia

Wallace Lai - University of Honk Kong

Xavier Derobert - University Gustave Eiffel

JULY 5 (WEDNESDAY)

9:00-12:30 **Registration**

9:30-10:45

Course From Ground to Cloud - The Future of GPR Processing in the Cloud

Hosts: Dr. Jan Francke and Lisandro Martinez, Geolitix

Collecting GPR data is only the first step in producing amazing and insightful results. GPR processing and interpretation is rightly regarded as part science and part art form. Join us for a comprehensive one-day course on the latest in GPR data analysis. The workshop will use Geolitix, a cloud-based processing and interpretation package that can handle large multi-channel datasets and perform complex operations nearly instantaneously. Learn the nuances of which filters are most effective on what types of datasets. Bring along your own datasets for the group to process together. Attendees will receive a one-month Geolitix subscription.

10:45-11:15 **Coffee break**

11:15-12:30

Course From Ground to Cloud - The Future of GPR Processing in the Cloud

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12:30-14:00 **Lunch**

14:00-16:30 **Registration**

14:15-15:00

Opening Ceremony

15:00-16:00

Novel developments in GPR systems and antennas

Chairs: Antonis Giannopoulos & Lorenzo Capineri

UAS-based GPR system

Alessandra Beni, Italy

This paper presents a Ground Penetrating Radar (GPR) system based on a drone, or Unmanned Aerial System (UAS). UAS-based GPR systems could represent the future in the field of GPR sensors, since such a platform enables automatized, remote surveys in all kinds of terrain. The prototype illustrated in this work have been developed using a commercial drone and a Vector Network Analyzer (VNA) based radar sensor. In order to test the system performances, joint experimental tests have been performed by using the prototype and a conventional GPR. The comparison between results obtained with the two sensors, are promising: the UAS-based prototype successfully detected underground targets. Although the conventional GPR outperforms the UAS-based prototype, the latter offers greater flexibility and versatility on non-regular areas.

DOA Estimation of an Inclined Conducting Cylinder with a Dipole Array Antenna in a Borehole

Satoshi Ebihara, Japan

We investigate the influence of a horizontally polarized wave's oblique incidence on the DOA estimation with a dipole array antenna in a borehole. According to a computer simulation, the horizontally polarized wave component of the reflected wave from conducting cylinder influences the wave's azimuth angle estimation. We conducted a field experiment in soil with a similar situation to the computer simulation. The experimental results confirmed the phenomena predicted by the computer simulation.

Depth performance analysis of GPR array featuring extended dynamic range

Davide Pasculli, Italy

GPR is one of the most reliable instruments to obtain information on underground utilities. In fact, amongst the various state-of-the-art methods available, it is a noninvasive technique capable of accurately locating both metallic and nonmetallic buried objects. As a result of the need for efficient systems for mapping subsoil utilities in areas with reduced maneuverability, such as sidewalks, squares, and pedestrian zones, a compact GPR array solution shall be used. The size constraints given by

such architecture impact on the radiant element design, implying a working bandwidth pretty well placed in UHF band, thus providing a reduced depth of investigation. Recently, a new system named Stream DP has been introduced to the market, designed to address the depth limitations of existing UHF GPR used for underground utility mapping. This new system has been designed with a new architecture to overcome the depth performance of the previous systems. This paper reports the description of the Stream DP GPR and performance comparison with its predecessor system, Stream C.

Q&A

16:00-16:30 Coffee break

16:30-16:45

The European GPR Association

16:45-18:00

Advanced data and image processing algorithms

Chairs: Craig Warren & Vânia Marecos

A novel web-based software for automated cloud processing, AI-assisted analysis and 3D visualization of GPR data

Alexandre Novo, Switzerland

The demand of GPR data processing tools has grown at a steady pace during the last two decades. However, it remained too niche due to complex workflows and lack of modern UX/UI design. This work introduces an innovative software platform with automated workflows using artificial intelligence for advanced analytics of any GPR data.

Determining of the subsurface object coordinates using 1Tx + 4Rx antenna system at incomplete set of reflections

Lorenzo Capineri, Italy

The impulse GPR with 1 transmitter and 4 receivers (1Tx+4Rx) antenna system is an important part of team of robots responsible for plastic mines detection. It is critical to provide reliability of its work even if only parts of 4 Rx antennas receive reflection from mine. The paper considers the possibility of improving the probability of detecting objects and determining its coordinates using UWB radar with 1Tx+4Rx antenna system in case if only two Rx antennas are able to register reflection from the mine.

A Full 3D Imaging Approach for Contactless GPR

Ilaria Catapano, Italy

This study deals with a full 3D imaging approach for contactless GPR data. The approach belongs to the family of linear microwave tomographic procedures, it takes into account the vectorial nature of the scattering phenomenon, and it exploits a ray-based model of the signal propagation in an inhomogeneous scenario. Specifically, the kernel of the integral equation to be inverted is evaluated by exploiting the concept of the interface reflection point. The formulation of the approach and numerical results, assessing the imaging capabilities, are provided.

Engineering and Geotechnical applications, e.g. utility detection, road and pavement inspection, concrete evaluation, NDT, tunnelling and mining (I)

Dual-Polarized Ground-Penetrating Radar Method for Sizing Cylindrical Metal Bars

Haihan Sun, Australia

Ground-penetrating radar (GPR) is a widely used non-destructive technique for detecting and locating subsurface metal bars in civil engineering structures. However, accurately characterizing the size of the metal bars remains a challenge for current GPR methods. In this work, we propose a new approach for estimating the diameter of metal bars using dual-orthogonally-polarized GPR systems. By establishing the theoretical relationship between the bar diameter and the power ratio of reflected signals acquired by perpendicular and parallel polarized antennas, the bar diameter can be estimated from the measured power ratio. The effectiveness of the method has been examined in different numerical scenarios. More experimental results will be presented at the workshop.

Q&A

18:00 **Cocktail**

JULY 6 (THURSDAY)

9:00-11:15 **Registration**

9:00-10:00

Engineering and Geotechnical applications, e.g. utility detection, road and pavement inspection, concrete evaluation, NDT, tunnelling and mining (I)

Chairs: Wallace Lai & Simona Fontul

Estimation of pipe orientation using GPR

Wenchao He, Hong Kong, China

Estimation of Ground Penetrating Radar (GPR) wave velocity and objects' depth plays an essential role when evaluating the condition of buried objects. Most processing methods are applied based on the assumption that the measurements are conducted perpendicular to the buried cylindrical targets. However, the object orientation substantially affected the hyperbolic reflection and the estimation of the depth and velocity. A few studies have used the hyperbola fitting method to map the orientations of embedded objects. In this paper, an optimization problem based on the ray-path reflection model was first established. Then, using a global optimizer, hyperbola fitting was conducted on numerical experiments. The object depth, GPR wave velocity and oblique angle were estimated. The results indicated fairly precise parameter predictions.

Leakage Detection Using Ground Penetrating Radar C-scan based on 3D Fuzzy C-Means Clustering

Yimin Zhou, Hong Kong, China

This paper presents an unsupervised change detection approach for underground leakage detection using ground penetrating radar (GPR) C-scan images. Superpixel and 3D fuzzy c-means are introduced in difference image(DI) generation and classification processes. Converting DI into superpixels reduces the negative influence of local random noise. The fuzzy c means algorithm was reformulated by introducing a spatial factor to involve 3D neighborhood information among adjacent slices. Experiments on field data demonstrate that the proposed algorithm has good capability to detect leakage areas in time series measurements.

On the Interoperability of GPR-based Infrastructure Monitoring and Simulation

Huamei Zhu, Australia

GPR has the proven ability to inspect invisible underground infrastructures such as utility tunnels and water pipelines. Simulation plays a critical role in interpreting GPR

mapping data while the digital model reconstruction remains a big challenge, particularly for complicated scenarios. To ease the modelling complexity, this study proposed a workflow to improve the interoperability between the graphical design application, the geotechnical analyser, and the electromagnetic (EM) simulator. Taking water pipe leakage detection as an example, the geometrical model was generated in Rhino and shared by FLAC3D for permeability simulation. Afterwards, coupling the graphical information by using a Grasshopper plug-in and the saturation results via the Complex Refractive Index Model (CRIM), an enriched dielectric model got reconstructed in gprMax for FDTD simulations.

Q&A

10:00-10:45

Keynote Lecture

Advanced and Challenges on GPR in Pavement Infrastructure

Andreas Loizos, Greece

Professor at National Technical University of Athens (NTUA)

The presentation reviews critical aspects of Ground Penetrating Radar (GPR) usage in pavement engineering. Over the years, GPR has proven its value as an innovative evaluation and diagnostic tool for pavement thickness assessment, density monitoring for QA/QC processes, defect detection, material characterization and other specific issued of pavement Infrastructures. Critical points, research achievements, current gaps and ongoing challenges stemming either from the stand-alone use of GPR or its integrated use with other nondestructive testing systems are presented. In the meantime, selected successful applications and innovations of GPR applications on pavement infrastructure asset construction and management are discussed for both roadways and airfields. In particular, the innovative and unique contribution of GPR is demonstrated for the post-rehabilitation assessment of a severely deteriorated non-conventional pavement structure and the condition assessment of airfield runways considering mechanistic principles for material characterization. Thereafter, the future of GPR for pavement condition assessment is described covering aspects including, among others, the joint consideration of GPR and satellite monitoring, the shift towards digitalization on the purpose of a more informed decision making, as well as the role of artificial intelligence (AI) for pavement performance modeling. The key role of the two dominant pillars, i.e., industry and academia towards the future of GPR and pavement infrastructure are critically discussed too.

10:45-11:15 Coffee break

11:15-12:30

Engineering and Geotechnical applications, e.g. utility detection, road and pavement inspection, concrete evaluation, NDT, tunnelling and mining (II)

Chairs: Xavier Derobert & Mercedes Solla

On the variants of SVM methods applied to GPR data to classify tack coat characteristics in french pavements: two experimental case studies

Grégory Andreoli, France

Among the commonly used non-destructive techniques, the Ground Penetrating Radar (GPR) is one of the most widely adopted today for assessing pavement conditions in France. However, conventional radar systems and their forward processing methods have shown their limitations for the physical and geometrical characterization of very thin layers such as tack coats. However, the use of Machine Learning methods applied to GPR with an inverse approach showed that it was numerically possible to identify the tack coat characteristics despite masking effects due to low time-frequency resolution noted in the raw B-scans. Thus, we propose in this paper to apply the inverse approach based on Machine Learning, already validated in previous works on numerical data, on two experimental cases with different pavement structures. The first case corresponds to a validation on known pavement structures on the Gustave Eiffel University (Nantes, France) with its pavement fatigue carousel and the second case focuses on a new real road in Vendée department (France). In both case studies, the performances of SVM/SVR methods showed the efficiency of supervised learning methods to classify and estimate the emulsion proportioning in the tack coats.

Link between Road Unevenness and Compaction investigated with Ground Penetrating Radar

Carl Van Geem, Belgium

Unevenness of road surfaces are a source of discomfort for the users, and to some extend even of safety hazards. Road administrations therefore put requirements on evenness in tenders. It seems accepted in the literature that roads in asphalt naturally present “long” wavelengths that are not so present in concrete roads. In this paper we present how we used Ground Penetrating Radar (GPR) for investigating the influence of compaction of bituminous layers on unevenness with “long” wavelengths.

A non-invasive and multi-scale approach to detect subsidence in pavements: InSAR, FWD and GPR

Alex Alonso Díaz, Spain

This paper presents a non-invasive and multi-scale approach to detect subsidence in a national road through the combination of complementary techniques, InSAR (Interferometric Synthetic Aperture Radar), FWD (Falling Weight Deflectometer) and

GPR (Ground-Penetrating Radar). For the InSAR, the PSI (Persistent Scatter Interferometry) method was selected using Sentinel-1 images. The FWD measurements were collected with 100 m spacing. The GPR survey was conducted with air-coupled antennas of 1.0 and 1.8 GHz central frequencies. The approach herein presented has demonstrated to be an efficient tool to detect subsidence: at network level, the InSAR allowed to detect differential settlements in transition zones and subsidence due to soil consolidation in high embankments; whereas, at project level, the GPR enabled to detect changes in the pavement structure, while the FWD measurements were used to differentiate weaker/stiffer pavement sections. This approach opens new possibilities for diagnostic procedures to optimize the measurement location of costly and time-consuming GPR and FWD tests.

Pavement Layer Interface Detection From GPR Data Using Deep Learning

Ahmed Elseicy, Spain

Ground penetrating radar (GPR) is a nondestructive test widely used for obtaining high-resolution profiles of roads. Pavement layer thickness measurement is vital information to assess the quality of new and existing pavement constructions. However, the automatic interpretation of pavement layer interfaces needs to be improved. This study proposes an automatic method to identify pavement layer interfaces using an image segmentation approach based on U-net models. Three models are evaluated, U-net, attention U-net, and R2-Unet. The models are trained and tested with real-world data. For the R2U-net-based model, the dice similarity coefficient and mean intersection over union (IoU) of the interface detection are 95.962% and 95.567%, respectively.

Q&A

12:30-14:00 Lunch

14:00-14:30

Poster Session

GPR Prospecting with an Innovative Use of the Point Markers: the Case of the Tumuli of Parabita, Italy

Raffaele Persico, Italy

In this contribution we describe an uncommon technique for making use of the marker points in GPR prospecting. This technique is based on a “stop-and-go”of the antennas described in the follow, and has been applied on three pre-historic Tumuli in the countryside of Parabita, a small town distant 40 Km from Lecce, Italy. The topography of the Tumuli has been evaluated from a photogrammetric reconstruction, which has allowed to account for the variations of height with respect to the surrounding planking level.

Searching for signs of an old wooden church in Breb,Maramureş

Dumitru Valentin Dragut, Romania

This paper presents a case study performed upon searching the foundation remnants of an approximately 400 years old lost wooden church, near Breb village in Maramureș, Romania, in the old area known as Copăciș. The site was investigated using a ground penetrating radar complemented with an aerial survey that offered 3D features.

Combination of GPR and LiDAR for the characterisation of building pathology in Cultural Heritage: the Hermitage of San Segundo (Spain)

Mercedes Solla, Spain

This work presents a combined study of complementary non-destructive techniques, GPR (Ground-Penetrating Radar) and Light Detection and Ranging (LiDAR). to analyze pathologies in a heritage building. The GPR survey was conducted with 2.3 GHz antennas. The Terrestrial Laser Scanner (TLS) used has a ±2 mm accuracy. LiDAR revealed a lateral thrust of the main nave of the hermitage, and moisture at the side wall of the altar. GPR allowed to determine the presence of moisture inside the wall. The joint interpretation of all the data allowed to highlight moisture as the cause of stone degradation, thus affecting the structural integrity of the nave. The interpretations thus obtained enables to define most appropriate maintenance interventions.

Using GPR for detecting a potential crypt beneath a paved church floor

Marjana Zajc, Slovenia

The discovery of written records mentioning an underground crypt beneath the floors of the Church of St. Margaret in Dol pri Ljubljani, Slovenia, lead to further investigations of the area. During a small-scale renovation of the church floor, an area filled with construction waste was discovered, suggesting the underground rooms may have

been filled in during one of the previous restorations. A GPR study was carried out inside the church in order to determine whether any air-filled chambers were still present beneath the church floor. Results showed the presence of an underground air-filled chamber, the existence of which was confirmed with a small telescopic camera, lowered through a drilled hole in the floor.

UAV data and GPR prospection for the study of a pre-historic necropolis in NW Portugal

Luís Gonçalves, Portugal

Over past decade, different remote sensing methodologies have been widely used in the detection, exploration and documentation of archaeological sites. Geophysical prospection, photogrammetric surveys and archaeological prospection and excavation are increasingly combined in several archaeological projects that serve both site investigation and dissemination of results. In this work, we present the results of Unmanned Aerial Vehicle (UAV) based survey and its integration with geophysical survey data from Ground Penetrating Radar (GPR), and some results from subsequent archaeological excavation, that were conducted in the study of Chã da Mourisca necropolis located in Ponte de Lima, NW Portugal. In this study photogrammetry by UAV enabled the accurate mapping of the necropolis area, with the production of high-resolution RGB orthomosaics and DSM's (Digital Surface Models). The GPR survey was conducted, over some selected areas, in a grid based prospection with parallel profiles acquired with 20 cm of separation.

Distorted hyperbola extraction of GPR data using edge detection for buried non-metallic pipes

Borui Guan, China

Non-metallic pipes are widely used in the urban underground pipe network. To map the pipeline system, obtaining the accurate locations and directions of the pipelines is an essential challenge. In this work, Ground Penetrating Radar (GPR) is used to detect buried non-metallic pipes since it is an efficient and non-destructive method for buried non-metallic pipes. Our aim with this paper was to develop a robust and automatic method to estimate the buried depth of non-metallic pipes with the extraction of hyperbolas in radargrams. The radargrams of buried non-metallic pipes with several angles (0 °, 30 °, 60 ° and 90 °) between the GPR survey line and the pipeline were compared numerically and experimentally. Edge detection with Canny operator was used for the automatic extraction of the hyperbolas reflected by buried pipes. The pixels of the edge detection image were adapted to the detection area. So, the buried depth of the pipes could be estimated by picking the pixel point of the hyperbola vertex accurately. The estimation results showed good accuracy with good shaped and distorted hyperbolas. It can also be extended to the detection of other buried objects.

Study on the GPR response of pipe leakage with the integration of CFD and FDTD

Renming Liu, China

This study proposed integrating CFD and FDTD to a numerically simulate the GPR response of pipe leakage in coastal sandy soil. CFD was used to model the water seepage of diffident pipe defects, while FDTD was applied to simulate radar wave propagation through the wet soil. It was observed that under the combined action of gravity and soil viscous resistance, the leakage area presents an ellipsoid with serrated edges. The corresponding radargram presented a bowl-shape strong reflection. The study proved the feasibility of using CFD and FDTD to construct more realistic seepage condition, and provide the reference for detecting pipe leakage.

The complementarity of GPR and MT-InSAR for pavement damage monitoring: preliminary results

Alex Alonso Díaz, Spain

This paper aims to draw conclusions about the complementarity of two Non-Destructive Testing (NDT) techniques, Ground-Penetrating Radar (GPR) and Multi-Temporal Interferometric Synthetic Aperture Radar (MTInSAR), in the detection of pavement failures. Regarding the MT-InSAR technique, two Persistent Scatterer Interferometry (PSI) cases were carried out using Sentinel 1A/B images with different orbital directions and temporal periods. The GPR survey was conducted with a ground-coupled antenna of 500 MHz. The results produced showed that the MT-InSAR technique allowed to highlight specific areas of the pavement under investigation, most certainly associated with structural changes. On the other hand, the GPR method allowed to detect different types of subsurface failures, which showed a good agreement with the scatters obtained from the MT-InSAR.

Use of GPR for rebars corrosion identyfication in concrete slabs: preliminary results

Anna Lejzerowicz, Poland

The article presents possibility of use of fully non-destructive method in order to rebars corrosion assessment in concrete slab. The tests were carried out on the slab with visible reinforcement corrosion using profometer (semi-destructive method because it requires contact of electrode with the rebar) and using ground penetrating radar, without contact to the rebars. The results were corelated – in the place where corrosion of rebar is clearly visible there is the biggest potential difference (based on profometer measurements) and the higher level of amplitude attenuation (based on GPR investigations). It means we can use only GPR method without support of semi-destructive tools in order to rebars corrosion location and quantitative assessment of the degree of reinforcement deterioration.

AI-based Graphical User Interface to detect debonded pavement sections from GPR B-scan data

Xavier Dérobert, France

In this paper, we present an AI-based Graphical user interface (GUI) devoted to B-scan data visualization, interpretation and classification of GPR data over debonded areas in the pavement structure. Two independent GUIs perform the processing of GPR data at two levels: gPRocessor and gprDetector. gPRocessor enables first an automatic preprocessing of the GPR data. It allows the operator to view, modify and update the data from any radar configuration in either time or frequency domains. The output B-scan processed data can be exported per user requirements. In the second stage, gprDetector implements the interlayer debonding detection on a scan-by-scan basis. Various supervised and unsupervised machine learning methods with suitable feature engineering techniques allow to classify A-scan data as either debonding or healthy zone. gprDetector includes a tool to label the data for defining the pseudo-ground-truth to be used for the performance assessment of the classification methods. Graphical results may be displayed at each processing stage to provide detailed information about the data. Both GUI tools were tested on the field data base in [1]

Structural assessment of pavements using a coreless GPR approach

Vânia Marecos, Portugal

The reliability of the estimated pavement moduli for structural assessment depends on the accuracy of layers thickness. In this paper the thickness of the bituminous layer was estimated using a coreless Ground Penetrating Radar (GPR) approach: the Common Mid-Point method with Air-Coupled antennas (CMP-AC), by combining multiple GPR offset configurations. For each survey line the thicknesses are estimated through a GPR testing campaign consisting of three passages with distinct antennas offsets. A dedicated processing methodology was implemented. The results obtained are promising as allow for detecting the changes between the designed and the estimated bituminous layer thickness. This methodology does not interfere with traffic flow, nor requires pavement coring. A case study of a flexible pavement is presented herein in which load tests performed with Falling Weight Deflectometer (FWD) were combined with GPR to assess the bearing capacity of the pavement. The structural models obtained initially using the design thickness were adjusted based on the CMP-AC approach leading to more realistic values for layer moduli.

GPR contribution for life cycle analysis through the evaluation of layer thickness variability

Vânia Marecos, Portugal

The residual life of a pavement is related with the pavement structure. The difference between the designed and real thickness of different layers, mainly of the bounded layers is crucial for the pavement assessment. In this paper an evaluation is presented regarding the influence of the bituminous layer thickness on the pavement residual life. A case study of a rehabilitated flexible highway pavement, in which surface cracking occurred only one year after reinforcement, is presented herein. It was

concluded that the thickness of the bound layers had a high influence on the estimated bituminous layers moduli. This illustrates the importance of the GPR tests to assess the pavement structure and consequently to enable a realistic evaluation of pavement life and behaviour.

In the width of the walls, in the depth of the soil - research project LAYERS (results from first sensitivity tests)

Rogério Mota, Portugal

LAYERS research project proposes to explore, using geophysical methods, such as ground penetrating radar (GPR), in the wall thickness and in the soil depth around buildings of heritage interest, the layers in which the history of constructive and decorative elements, such as azulejo, may be resolved. In this paper, the results of some GPR sensitivity tests are presented. These tests were performed at LNEC campus and at Museu do Azulejo, on walls covered with azulejo, ceramic pieces, clay bricks and clay tiles, and on floors covered by tiles and stone slabs, in order to evaluate the ability of GPR to distinguish the different types of wall and floor coverings in historic buildings.

Detecting unregistered underground infrastructure with GPR

Maria João Coelho, Portugal

A common problem in urban environments, especially in old streets and buildings that have been subjected to several interventions over time, is the lack of a register (or its update) of underground infrastructures. The GPR can be critical in identifying these subsurface structures of uncertain location and should be used in the planning and programming of direct survey and excavation work at these sites. This paper presents an application of GPR in the search for underground infrastructures in one of the courtyards of the Palácio das Necessidades (18th century palace) in Lisbon. Based on the results obtained, it was possible to identify a suitable area for burying containers of municipal solid waste in the inspected yard.

Numerical Modelling for Masonry GPR Surveys

Davide Campo, United Kingdom

Apparently complex reflection patterns can be common in GPR structural surveys. The main reasons for that are the regular geometrical shapes of structural and non-structural elements and the high frequency systems employed. These imply a greater direct and indirect signal interaction with materials: typical examples are multiples created by relatively thin layers, not otherwise visible with low frequency systems. This paper presents a case study where a radargram collected on a masonry wall of a historical building exhibited crisscross or “X” reflection patterns. It was the only wall in the building where these patterns were observed. Based on assumptions relying on a priori knowledge of the building structure gained by means of GPR scans conducted on adjacent walls, numerical modelling was employed to verify a hypothesis that could explain the observed data.

Full Porarimetric Borehole Radar Measurement of Conducting Cylinder with Dipole and Loop Antenna

Satoshi Ebihara, Japan

We present full polarimetric borehole radar and field experiment results with this radar. This radar consists of four dipole and two loop array antenna elements for each transmitter and receiver. We conducted field experiments to measure a conducting cylinder in soil with the radar. The experimental data showed the co-polarization components are larger than the cross-polarization ones in magnitudes of reflection from a vertical conducting cylinder. It also showed that the cross-polarization components in an inclined conducting cylinder reflection got larger than that in the vertical conducting cylinder. These results agree with the polarimetric property in conducting cylinder scattering. Also, we confirmed the experimental data was in line with the reciprocity theorem.

14:30-15:30

Demos Session

IDS Georadar

Impulse Radar

15:30-16:00

Proposal for IWAGPR 2025

16:00-16:30 Coffee break

16:30-18:00

Engineering and Geotechnical applications, e.g. utility detection, road and pavement inspection, concrete evaluation, NDT, tunnelling and mining (III)

Chairs: Christina Plati & Carl van Geem

Impact of stress on radar signal in concrete

Aleth Confais, France

Prestressed concrete is present in many civil engineering structures such as dams or containment buildings. Due to the ageing of structures (creep, shrinkage, corrosion), prestressing losses can occur. Thus, it is crucial to be able to know the stress state in order to ensure structural safety. The current techniques, such as the crossbow test used for assessing the tension in the prestressing cables, are semi-destructive. However, some structures, such as containment buildings cannot withstand intrusive testing. Thus, it is necessary to use nondestructive techniques to assess the concrete

stress to monitor the prestressing losses. The aim of this study is to assess the concrete stress variations by electromagnetic techniques. More practically, the study focuses on the impact of compressive stress on the propagation of Ground Penetrating Radar (GPR) waves in concrete. The measurements are done with GPR antennas with a center frequency of 1,5 GHz and a Vivaldi antenna on concrete specimens under compressive stress. Tests are performed on ambient and dry samples with different orientations of the antennas compared to the loading direction. Results show that an increase in stress induces a decrease in amplitude, but no time offset of the signal. These outcomes are observed during the loading as well as during the unloading. However, these results depend on the hydric state of the slab. Indeed, in comparison, the signals on the dry slabs do not vary with the stress.

Moisture concrete analysis in a damaged concrete slab

Sonia Santos-Assuncao, United Arab Emirates

Ground-Penetrating Radar (GPR) is an excellent tool to non-destructively detect the embedded rebar in concrete. Almost all civil engineering structures, including building, bridges and pavements, count with reinforced concrete or other steel reinforcement structural components. Water infiltration is a silent problem, what can cause serious irreversible and relevant damage in any reinforced concrete structures. GPR is the fastest method and with a high resolution to detect this type of problem. In the present work, the GPR was used to inspect a building under construction, with underground water filtration. Taking advantage of the GPR signal attenuation effect caused by the water content, and creating a 3D model, the GPR survey allowed detection and mapping the water filtration and the damages in different structure zones. The result of this survey helps to identify the damage range, location and depth, in the affected structure. Allowing accurate diagnosis for an adequate actuation.

Cases study about corrosion analysis in structures

Vega Perez-Gracia, Spain

Corrosion appears in many structures because iron and steel have been used throughout history to reinforce buildings and structures. GPR is a suggested NDT tool to detect the damage in the early stages, before the appearance of cracks on the surface of structural elements. The effects of corrosion on radar images are usually an important decrease in the amplitude of the reflected wave. In some cases, the anomaly even disappears, and the target cannot be detected. Another effect, most likely associated with the increase of water content in the medium is a lower wave velocity (obtaining higher travel times.

Automatic detection of reinforcement rebar and material type characterization in concrete slab based on frequency analysis

Sonia Santos-Assuncao, Hong Kong

Ground-Penetrating Radar (GPR) is an excellent tool to non-destructively detect the embedded rebar in concrete. Almost all civil engineering structures, including building, bridges and pavements, count with numerous rebar. The location and extraction of the position can be long and tedious. Several efforts were successfully carried out to automatically detect the rebar position in the time-domain. Here it is presented a new methodology to automatically detect the horizontal position of rebar through the frequency analysis – Fast Fourier Transform (FFT). The technique is quick and user-independent: it can be applied to the full A-scan, without selecting a specific time window. It was observed that both the amplitude and the integral of the FFT achieve maximum values when the wave intercepts the position of where a reinforcement rebar is located. The technique was tested in 2 cases, for rebar distributed with different spacing intervals and depth, several centre frequencies and both impulse radar and step frequency continuous wave GPR antennas. Apart of the rebar detection, the technique was able to distinguish between plastic and metal.

Case Studies and Lessons on Using the GPR Method on Hydropower Dams in Romania

Alexandra Gerea, Romania

When it comes to hydropower dams there is a variety of ways in which the GPR method can be applied but there are no standard norms at the moment or good practices that can be easily or universally applied on the hydropower dams in Romania. A variety of hydropower dams have been chosen to test and assess if linear profiles on the dam's crest prove to be an efficient way of applying the GPR method that can represent a first step in assessing the dams. Two types of antennas have been tested, 200 MHz and 400MHz antennas with the purpose of checking for details at the very surface of the crest and understanding what kind of features can be easily seen and tracked and what features are less visible.

Complementing GPR detection of tree roots in urban areas

Andrei Mihai, Romania / UK

Trees provide valuable environmental environmental services, particularly in urban areas, which can be affected by the urban heat island effect and higher levels of pollution. However, roots can also be disruptive to infrastructure as their roots can cause subsidence, cracks, and displacements. Geophysical methods can help to detect and map the location of roots in relation to these systems, which can inform maintenance and repair decisions and help to prevent costly and disruptive repairs. Ground Penetrating Radar (GPR) has emerged as the most promising method that can help to identify the presence and extent of roots, but while much of the literature focuses on the potential of this application, its limitations and possible complements are less discussed. Here, we discuss how other methods (most notably, electrical

resistivity imaging) could be used to complement GPR in the detection and mapping of urban tree roots.

Q&A

19:00 **Dinner**

Restaurant Ordem dos Médicos

www.pateovelho.pt

JULY 7 (FRIDAY)

9:00-11:15 Registration

9:00-10:00

Forward modelling techniques and inversion methodologies + Security applications, unexploded ordnance and landmine detection

Chairs: Evert Slob & Vega Pérez-Gracia

Optimized full-waveform inversion method for characterization of the waterproofing membrane in bridges

Viktoriia Buliuk, France

The purpose of this article is to present an Ultra-Wide Band GPR (ground-penetrating radar) technology in combination with an improved simplified Full-Waveform Inversion (FWI) approach for evaluation of bridge deck waterproofing membrane. gprMax model is used as a numerical forward model applied on various case studies corresponding to experimental configurations made in the laboratory. FWI has been designed and simplified for the 2D model. The structure under consideration is one-dimensional. This study have proved that the method is applicable to various multi-layered media configurations (various materials and structures). In this problematic, the FWI approach allows to evaluate and monitor the required dielectric and geometric parameters of the structure from a temporal signal (A-scan) with high accuracy and less time consuming. This punctual evaluation is needed for the next processing step, that is not discussed in this paper, based on Machine Learning method to detect automatically defects in bridge deck waterproofing membranes.

Simulation of GPR scattering from an object buried inside a layered medium with the GPILE method

Nicolas Pinel, France

This paper analyses the electromagnetic (EM) wave scattering from an object buried between two random rough interfaces. We present a rigorous numerical EM model based on the boundary integral equation method that separates the different sensed media, which is discretized by the method of moments. The resulting linear system is resolved by a fast method called GPILE (Generalized Propagation Inside Layer Expansion), which makes it possible to reduce the complexity of the inversion of the impedance matrix and to isolate the different contributions to the overall scattering process. This method is then applied to a roadway sensed by GPR, with a view to calculating its time-domain response. The practical objective of this analysis is to study the impact of an embedded object inside a complex multilayered medium on the GPR signal.

Error assessment of microwave holography inversion for shallow buried objects

Emanuele Vivoli, Italy

Holographic imaging is a technique that uses microwave energy to create a three-dimensional image of an object or scene. This technology has potential applications in land mine detection, as the long-wavelength microwave energy can penetrate the ground and create an image of hidden objects without the need for direct physical contact. However, the inversion algorithms commonly used to digitally reconstruct 3D images from holographic images, such as Convolution, Angular Spectrum and Fresnel, are known to have limitations and can introduce errors in the reconstructed image. Despite these challenges, the use of holographic radar at around 2 GHz in combination with holographic imaging techniques for land mine detection allows to recover size and shape of buried objects. In this paper we estimate the reconstruction error for the convolution algorithm based on hologram imaging simulation, and assess this errors recommending an increase in the scanner area, taking into account the physical constrains that it posses and the expected error reduction.

Q&A

10:00-10:45

Keynote Lecture

Drone-borne ground-penetrating radar full-wave modeling and inversion for digital soil mapping

Sébastien Lambot, Belgium

Full-Professor (part-time) and an FNRS Research Director at the Université catholique de Louvain

In recent years, there has been an increasing need to better understand water dynamics and improve soil and water resource management. Characterizing soil properties with high resolution at the field scale is critical for achieving these objectives. Ground-penetrating radar (GPR) has emerged as a promising technique for this purpose, as it allows for fast, high-resolution mapping of soil properties. In this context, the studies presented here focus on the development and application of drone-borne GPR systems for soil moisture and electrical conductivity mapping. These studies aim to demonstrate the potential, benefits and limitations of GPR for soil characterization at the field scale, and to provide insights into the factors that influence GPR measurements and inversion. By improving our understanding of GPR techniques, we can enhance our ability to manage soil and water resources more effectively. Our studies collectively demonstrate the potential of drone-borne GPR for high-resolution soil moisture and electrical conductivity mapping at the field scale, and its application in precision agriculture and environmental monitoring. The first study presents a new drone-borne GPR system for soil moisture mapping, which consists of a handheld vector network analyzer, a hybrid horn-dipole antenna, a GPS, a

microcomputer, and a smartphone for remote control. Soil moisture is derived using full-wave inverse modeling based on the full-wave radar equation and **multi-layered** media Green's functions. The obtained soil moisture maps are in good agreement with the topographical conditions of the fields and aerial orthophotography observations. The second study investigates the effect of radar incident angle on full-wave inversion for soil permittivity characterization. Numerical analyses and field measurements show that errors in permittivity estimation can be significant as a function of the antenna radiation pattern and the incident angle. However, if the incident angle is known and the characteristic antenna functions are determined as a function of the incident angle, full-wave modeling and inversion remain accurate. The third study analyzes low-frequency drone-borne GPR and full-wave inversion for soil electrical conductivity mapping. The results show that the soil surface reflection is significantly more sensitive to soil electrical conductivity than to soil permittivity within the frequency range of 15-45 MHz. Field measurements using low-frequency drone-borne radar with a 5-m half-wave dipole antenna and electromagnetic induction (EMI) measurements show that the soil conductivity maps obtained by the proposed GPR and EMI are compliant in terms of absolute values and spatial patterns. Finally, the fourth study analyzes the effect of trench-hill soil surface on GPR full-wave inversion for soil moisture measurement. Numerical experiments show that the trench-hill surface only slightly affects the inversion when the frequency is lower than 190 MHz, in agreement with Rayleigh's criterion. Field measurements using a prototype radar mounted on an irrigation robot demonstrate promising perspectives for automated and real-time determination of root-zone soil moisture in potato fields, and thereby for precise and automatic irrigation. Overall, the studies demonstrate the potential and benefits of drone-borne GPR for fast, high-resolution mapping of soil moisture and electrical conductivity at the field scale, and their application in precision agriculture and environmental monitoring.

10:45-11:15 Coffee break

11:15-12:30

Geological and environmental applications, e.g. geology, sedimentology, hydrogeophysics, soil contamination, glaciology, and planetary exploration (I)

Chairs: Raffaele Persico & Maria João Coelho

Detection and Characterization of Simulated Clandestine Burials using GPR

Evert Slob, Netherlands

We conducted ground penetrating radar (GPR) surveys to detect the presence of simulated clandestine burials at the Amsterdam Research Initiative for Subsurface Taphonomy and Anthropology (ARISTA) test facility. Our aim is to determine the characteristic responses of the simulated clandestine burials in this man-made sandy environment (reclaimed land) and use them to provide recommendations for forensic

investigations. We performed GPR surveys over three simulated clandestine burials at ARISTA during four nonconsecutive days. The acquired data represent common-offset data to investigate changes to burial detectability depending on central antenna frequency (250 MHz and 500 MHz), different GPR instruments (NOGGIN or pulseEKKO), changes to survey grid orientation relative to burials, and increased soil moisture content in the survey area. In common-offset radargrams the burial anomalies take on many forms, appearing as disruptions to existing features (direct-wave arrivals and soil horizons) and as isolated reflection events (hyperbolic events and burial-length horizontal anomalies). In time slices, the burials are characterized by high- or low-amplitude rectangular anomalies. When used in conjunction, the radargrams and time slices produce characteristic responses consistent with the locations of the burials, regardless of the survey grid orientation. Increased soil moisture at the site improves the detectability of the burials.

3D GPR to explore peat deposits: Strategies for data acquisition, processing, and interpretation

Philipp Koyan, Germany

In soil sciences and geology, ground-penetrating radar (GPR) reflection data are routinely used to explore the shallow subsurface. Recognizing that peatlands represent an important part of the global climate system, there is an increasing need to investigate and characterize peat deposits in more detail. Up to today, the application of GPR in peatland studies focuses on collecting 2D data along selected lines to develop models of peat thickness and stratigraphy. We present a 3D GPR case study from a peatland in northeastern Germany where we develop a detailed 3D model of the investigated peat body. Our results show significant variations in peat thickness including a prominent circular depression structure. We conclude that such structures could not be reliably imaged using 2D GPR surveying strategies. Thus, our results highlight the benefit of 3D GPR surveying to develop a more profound understanding of peat deposits and their characteristics.

Time-lapse GPR imaging of subsurface flow processes during a hillslope irrigation experiment

Sophie Marie Stephan, Germany

For a better understanding of hydrological processes in the subsurface, hydrologists need information on different spatial and temporal scales. Geophysical methods provide the opportunity to image and monitor subsurface flow processes beyond point information. In particular, ground-penetrating radar (GPR) is a promising method because it allows for fast data acquisition paired with high spatial resolution. Such characteristics are considered to be critical when monitoring fast temporal and small spatial changes in the subsurface. In this study, we present a field data example of time-lapse GPR reflection measurements to monitor subsurface flow processes induced by an irrigation experiment. We use similarity attributes to analyze our recorded data and to visualize drainage dynamics at a hillslope section in the Ore Mountains, Germany. Our results demonstrate the feasibility of GPR measurements

to provide spatio-temporal information on subsurface flow processes at spatial scales of a few decimeters and at temporal scales of a few minutes.

Characterization of heterogeneous subsurface with broad-band GPR: application to WISDOM, the GPR of the ExoMars mission

Emile Brighi, France

This paper presents a new method to retrieve the typical sizes and the contrast of permittivity value of fractal heterogeneities in the subsurface using the broad frequency band of Ground Penetrating Radars.

Q&A

12:30-14:00 Lunch

14:00-15:30

Geological and environmental applications, e.g. geology, sedimentology, hydrogeophysics, soil contamination, glaciology, and planetary exploration (II) + Archaeology and cultural heritage

Chairs: Nectaria Diamanti & Rogério Mota

GPR measurements in drifts at the southern part of the Morsleben salt structure

Volker Gundelach, Deutschland

Allertal salt structure, used as repository for nuclear waste, was explored from the surface by seismic measurements, ground openings and boreholes. Due to the accuracy of these investigations, the internal salt structure is known. The complex geological structures (bent, folded, sometimes faulted layering of salt, potassium, clay, and anhydrite) in low-conductive salt can be mapped if distance and direction of reflecting objects are known. In focus of interest is the distribution of anhydrite layers in the center of the salt structure. Underground, GPR (Ground penetrating radar) is an efficient and precise nondestructive tool for the exploration of salt deposits. With geophysical results and some geological knowledge a three dimensional model of the salt structures can be created.

Advancements in Using Deep Learning Methods for GPR Detection of Tree Roots

Livia Lantini, United Kingdom

In recent years, the effects of emerging diseases have caused significant worries among environmentalists and communities, requiring putting efforts into the monitoring and management of natural resources. In this regard, tree roots are one of the most vital and fragile organs of the tree, as well as one of the most complex to investigate.

In this way, non-destructive testing (NDT) methods have become one of the most popular techniques for assessing and monitoring tree roots, as opposed to conventional destructive techniques. In this context, ground penetrating radar (GPR) applications have proved to be precise and effective for investigating and mapping tree roots. The inhomogeneity of the soil, however, is a significant obstacle towards the GPR identification of tree roots, and a deep learning (DL)-based method has been recently proposed to tackle this issue. This research, therefore, aims to improve upon the above-mentioned approach, by customising two convolutional neural networks (CNN) methods for the analysis of GPR spectrograms. In this study, the GPR signal is first processed in both the temporal and frequency domains to filter out noise-related information, and subsequently spectrograms are generated. Afterwards, two specifically modified CNN classifiers are implemented and then compared to other DL methods, already validated for tree roots detection. The findings of this study further support the viability of the suggested methodology and open the way for the application of new approaches for evaluating tree root systems.

Combined time-depth conversion applied to the reconstruction of buried cavities

Raffaele Persico, Italy

In this contribution we propose a time-depth conversion method accounting for the occurrence of a not constant signal propagation velocity in the investigated scenario. In particular, we will consider simulated data referred to a scenario with a large cavity and provide results showing the available improvement in imaging it. The method is not rigorous from a mathematical point of view but it is promising especially in presence of strong and large scattering targets. These anomalies might hinder the convergence of iterative focusing algorithms. In addition, a migration algorithm might not provide satisfying results due to nonlinear effects and due to some side-effects of the pre-processing (meant here as the processing steps before the migration) performed on the data.

Are Lunar Penetrating Radar data so unusual? Some relevant issues about their processing and analysis

Emanuele Forte, Italy

We focus on some processing and analysis issues of Lunar Penetrating Radar collected in the Chang'E-4 Chinese lunar mission on the farside of the Moon, in the ancient Van Kármán crater. The rover equipped with the radar system stops frequently and for long times thus recording a lot of duplicated traces. A dedicated strategy to remove redundant data is implemented and successfully applied. Even after complete removal of duplicated traces, peculiar mirror features due to some almost opposite paths of the rover still remain in the radar profile, and must be carefully considered during data interpretation. We further analyze the effectiveness of migration finding that it is not a crucial processing step for the considered dataset both for imaging of reflectors and diffraction focusing. On the other hand, signal attributes can be

successfully exploited not only to improve and constrain data interpretation, but also to implement automated reflection picking strategies.

Full-Polarization Analysis for Chang'E-4 Lunar Penetrating Radar Data Acquired during the Rover Turnings

Haoqiu Zhou, China

The lunar penetrating radar(LPR) onboard the Chang'E-4 (CE-4) probe provides a unique opportunity to map the shallow lunar structures on the far side of the Moon with high resolution. However, due to the timed-triggered acquisition mode, the LPR kept acquiring data when the rover was turning and stopped. In this study, we innovatively extracted the polarimetric scattering matrix from the data acquired at different orientations at the same location during rover turning. Subsequently, we quantify the regolith maturity within 24 m depth based on the Freeman decomposition results. The results provide new insights of the evolution of lunar regolith at landing site.

GPR tests in agricultural soils

Vega Perez-Gracia, Spain

Several lab tests are applied to determine relations between GPR data and physical properties of agricultural soils. Soil water content and porosity were related to different parameters: the wave velocity, the frequency of the received signal and changes in the signal amplitude. Experimental data was compared to theoretical and empirical models.

Q&A

15:30-16:30 Coffee break and Porto wine

16:30-17:30

Best Student Paper Award & Closing Ceremony

http://iwagpr2023.lnec.pt/