EGU2016

GI3.1 Abstracts

23 Jan 2016 00:12:14

Geophysical Research Abstracts
Vol. 18, EGU2016-4277, 2016
EGU General Assembly 2016

Analysis of Human's Motions Based on Local Mean Decomposition in Through-wall Radar Detection

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Observation of human motions through a wall is an important issue in security applications and search-and rescue. Radar has advantages in looking through walls where other sensors give low performance or cannot be used at all. Ultrawideband (UWB) radar has high spatial resolution as a result of employment of ultranarrow pulses. It has abilities to distinguish the closely positioned targets and provide time-lapse information of targets. Moreover, the UWB radar shows good performance in wall penetration when the inherently short pulses spread their energy over a broad frequency range.

Human's motions show periodic features including respiration, swing arms and legs, fluctuations of the torso. Detection of human targets is based on the fact that there is always periodic motion due to breathing or other body movements like walking. The radar can gain the reflections from each human body parts and add the reflections at each time sample. The periodic movements will cause micro-Doppler modulation in the reflected radar signals. Time-frequency analysis methods are consider as the effective tools to analysis and extract micro-Doppler effects caused by the periodic movements in the reflected radar signal, such as short-time Fourier transform (STFT), wavelet transform (WT), and Hilbert-Huang transform (HHT).The local mean decomposition (LMD), initially developed by Smith (2005), is to decomposed amplitude and frequency modulated signals into a small set of product functions (PFs), each of which is the product of an envelope signal and a frequency modulated signal from which a time-vary instantaneous phase and instantaneous frequency can be derived. As bypassing the Hilbert transform, the LMD has no demodulation error coming from window effect and involves no negative frequency without physical sense. Also, the instantaneous attributes obtained by LMD are more stable and precise than those obtained by the empirical mode decomposition (EMD) because LMD uses smoothed local means and local magnitudes that facilitate a more natural decomposition than that using the cubic spline approach of EMD.

In this paper, we apply the UWB radar system in through-wall human detections and present a method to characterize human's motions. We start with a walker's motion model and periodic motion features are given the analysis of the experimental data based on the combination of the LMT and fast Fourier Transform (FFT). The characteristics of human's motions including respiration, swing arms and legs, and fluctuations of the torso are extracted. At last, we calculate the actual distance between the human and the wall.

This work was supported in part by National Natural Science Foundation of China under Grant 41574109 and 41430322.

Geophysical Research Abstracts
Vol. 18, EGU2016-6072, 2016
EGU General Assembly 2016

Procedure for detecting underground utilities with specific shape

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Nowadays GPR technology is acknowledged as a reliable, fast, non-destructive remote sensing technology whose area of applications is wider every day. One of its most common applications is underground utility detection. Not only it is possible to detect the utility in the field, but using certain algorithms utilities which haven't been detected in the field can be detected in radargrams. There is a number of procedures for automated detection of utility in the radargrams. Further, there are procedures that can estimate certain parameters such as propagation velocity, diameter or even characteristics of the material.

However, the majority of these procedures is designed to detect cylindrical shape utilities, which, in a radargram, are represented with hyperbolic reflection. According to geometry of hyperbola, utility parameters can be estimated.

In this paper we present a procedure that is designed to estimate characteristics of non-cylindrical utilities. It is worth mentioning that these utilities are not so rare. Some underground tanks and sewage collectors are among them.

Heat line is consisted of two insulated pipes of the same diameter, often placed in a concrete channel and covered with plates made from reinforced concrete. Therefore, it can be considered as non-cylindrical utility and such structure has characteristic signature in a radargram. The main idea of the proposed procedure is to detect this signature, and then, based on standardized parameters for the heat lines, to estimate the diameter of the pipes.

The proposed procedure is based on artificial neural network. As a training set we made a number of radargrams collected on different locations which contain heat lines of various dimensions. Pipe diameters were in a range from 65 to 250 mm. 400MHz antenna was used since the depth hasn't exceeded 2m. After the network is trained it is validated using radargrams that haven't been used in the training set. Further tests were done with radargrams that contained none, one or several heat lines.

Experiments showed that it is possible to automatically detect heating lines in a radargram and later, based on detection results, to estimate the diameter of the pipes using standard heat line dimensions.

This paper is a contribution to the 2016 EGU GA Session GI3.1 "Civil Engineering Applications of Ground Penetrating Radar," organized by the COST Action TU1208

Geophysical Research Abstracts
Vol. 18, EGU2016-12565-1, 2016
EGU General Assembly 2016

Development of SAP-DoA techniques for GPR data processing within COST Action TU1208

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This work focuses on the use of Sub-Array Processing (SAP) and Direction of Arrival (DoA) approaches for the processing of Ground-Penetrating Radar data, with the purpose of locating metal scatterers embedded in concrete or buried in the ground. Research activities have been carried out during two Short-Term Scientific Missions (STSMs) funded by the COST (European COoperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" in May 2015 and January 2016.

In applications involving smart antennas and in the presence of several transmitters operating simultaneously, it is important for a receiving array to be able to estimate the Direction of Arrival (DoA) of the incoming signals, in order to decipher how many emitters are present and predict their positions. A number of methods have been devised for DoA estimation: the MUltiple SIgnal Classification (MUSIC) and Estimation of Signal Parameters via Rotational Invariance Technique (ESPRIT) are amongst the most popular ones [1]. In the scenario considered by us, the electromagnetic sources are the currents induced on metal elements embedded in concrete or buried in the ground. GPR radargrams are processed, to estimate the DoAs of the electric field back-scattered by the sought targets. In order to work in near-field conditions, a sub-array processing (SAP) approach is adopted: the radargram is partitioned in sub-radargrams composed of few A-scans each, the dominant DoA is predicted for each sub-radargram. The estimated angles are triangulated, obtaining a set of crossings with intersections condensed around object locations. This pattern is filtered, in order to remove a noisy background of unwanted crossings, and is processed by applying the statistical procedure described in [2].

We tested our approach on synthetic GPR radargrams, obtained by using the freeware simulator gprMax implementing the Finite-Difference Time-Domain method [3]. In particular, we worked with the reference data of TU1208 Concrete Cells 1.1-1.3 [4]. Preliminary results and a description of the method have been presented in [5]. Further results have been obtained by processing radargrams obtained in the presence of modified versions of the TU1208 Concrete Cells, where we changed the positions of the reinforcing elements. As expected, we achieved better results when the distance between the scatterers was larger and their interaction weaker. By analysing in depth the results obtained for the enlarged versions of Cells 1.1-1.3, we could assess in a comprehensive way the accuracy and limits of our approach in the presence of multiple scatterers, versus their relative distance.

During future STSMs, we look forward to testing our approach on experimental data. We also plan to improve the method, in order to exploit in a more advanced way the multi-frequency information enclosed in the GPR data. A final STSM will be devoted to implementing a graphical-user interface and writing a user manual, as we intend to release our codes for free public download by the end of the Action.

Acknowledgement

The Authors are grateful to COST - European COoperation in Science and Technology (www.cost.eu) for funding the Action TU1208 "Civil engineering applications of Ground Penetrating Radar" (www.GPRadar.eu).

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Geophysical Research Abstracts
Vol. 18, EGU2016-12787, 2016
EGU General Assembly 2016

O' Connell bridge inspection by means of Ground Penetrating Radar

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Ground Penetrating Radar (GPR) is a well-known technique successfully applied in different areas. In structural inspection the methodology may expose information about structural arrangement and pathologies.

GPR emits high frequency electromagnetic impulses allowing to detect changes on the electromagnetic properties: electrical conductivity, dielectric constant and magnetic permeability. The central frequency of the each antenna is characterized by a specific resolution and penetration depth. Therefore, different scales of structures can be analysed. High frequency antennas output high resolution images/signals about the shallowest elements such as rebar and the thickness of the first layer. On the other hand, intermediate or lower frequency antennas locate deeper structures, such as the thickness of the arch. The compilation of distinct frequencies gives a better understanding and a more accurate detection of elements in the inner structure.

O'Connell Bridge (1877) is one of 24 bridges along River Liffey and one the most famous historical structures in Dublin. It is composed by sandstones and granite and covered by asphalt which represents a suitable structure to evaluate by means of GPR. The lack of inner structural information, especially the thickness of the layer, presence of reinforcement or other metallic elements of support required, at least, a dual frequency analysis of the bridge. In this case, it was applied the (200 MHz and 600 MHz) Multi-Channel Stream EM combined with 1.6 GHz GSSI high frequency antenna.

The inspection of bridges by means of GPR may provide not exclusively interesting structural data but historical information and the state of conservation.

Geophysical Research Abstracts
Vol. 18, EGU2016-14884, 2016
EGU General Assembly 2016

Observing of tree trunks and other cylindrical objects using GPR

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Trees are a part of our everyday life, hence it is important to prevent their collapse to protect people and urban infrastructures. It is also important to characterize tree wood properties for usages in construction. In order to investigate internal parts of tree trunks non-invasively, ground-penetrating radar (GPR), or in this case, ultra-wideband microwave radar as a general tool, appears to be a very promising technology. Nevertheless, tree trunk tomography using microwave radar is a complicated task due to the circular shape of the trunk and the very complex (heterogeneous and anisotropic) internal structures of the trunk. Microwave sensing of tree trunks is also complicated due to the electromagnetic properties of living wood, which strongly depend on water content, density and temperature of wood. The objective of this study is to describe tree trunk radar cross sections including specific features originating from the particular circumferential data acquisition geometry. In that respect, three experiments were performed: (1) numerical simulations using a finite-difference time-domain software, namely, gprMax 2D, (2) measurements on a simplified laboratory trunk model including plastic and cardboard pipes, sand and air, and (3) measurements over a real tree trunk. The analysis was further deepened by considering: (1) common zero-offset reflection imaging, (2) imaging with a planar perfect electrical conductor (PEC) at the opposite side of the trunk, and (3) imaging with a PEC arc at the opposite side of the trunk. Furthermore, the shape of the reflection curve of a cylindrical target was analytically derived based on the straight-ray propagation approximation. Subsequently, the total internal reflection (TIR) phenomenon occurring in cylindrical objects was observed and analytically described. Both the straight-ray reflection curve and TIR were well observed on the simulated and laboratory radar data. A comparison between all experiments and radar configurations is presented. Future research will focus on the design of an adapted radar antenna for that application to optimize living tree trunk tomography.
This research is funded by the Fonds de la Recherche Scientifique (FNRS, Belgium) and benefits from networking activities carried out within the EU COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar".

Geophysical Research Abstracts
Vol. 18, EGU2016-16178-1, 2016
EGU General Assembly 2016

A guidelines handbook for GPR surveys in tunnels: a COST Action TU1208 contribution

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A significant open issue concerning the reliability of geophysical methods and in particular of ground penetrating radar (GPR), both in research and professional context, is a general lack of international standards. This is a major problem to be faced, in order to gain scientific strictness for the GPR practices, and to easily extend to the international community the results achieved within the area of single virtuous countries. Producing international guidelines can represent an important step forward, in this sense.

In the memorandum of understanding of the COST Action TU1208 is clearly stated that one of the main purposes of the Action is the "development of innovative protocols and guidelines which will be published in a handbook and constitute a basis for European Standards, for an effective GPR application in CE tasks; safety, economic and financial criteria will be integrated within the protocols". Of course this is not a simple task to be accomplished. Firstly, survey procedures are highly dependent on the objective of the survey itself. On the basis of the objective of each geophysical test, the GPR system, the antenna configuration, and even the processing procedures may change. Besides, these procedures are also influenced by the environmental conditions in which the tests are performed. This affects several aspects spanning from hardware to software, but including, for instance, also safety issues. Due to these reasons, one of the main goal of the COST Action TU1208 is the development of several guidelines related to the main applications of GPR in the field of civil engineering.

In this work, the structure of a guidelines handbook for GPR activities in tunnels is outlined. In the first sections, the principal references in the field are provided, and the most common GPR equipment and complementary technologies are described. Subsequently, the survey methodologies are explained. Particular attention is paid to the preliminary activities to be carried out prior to the GPR surveys, which can cover an important role in such a complex environment. Lastly, the main applications of GPR technology in tunnels are discussed.

Acknowledgement

The Authors thank COST, for funding the Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar."

Geophysical Research Abstracts
Vol. 18, EGU2016-16258, 2016
EGU General Assembly 2016

Reconstruction of Vertical Profile of Permittivity of Layered Media which is Probed Using Vertical Differential Antenna

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Results of this research are intended to use at GPR investigations of layered media (for example, at roads' inspection) for the processing of collected data and reconstruction of dependence of permittivity on the depth.
Recently, an antenna system with a vertical differential configuration of receiving module (Patent UA81652) for GPR was suggested and developed The main advantage of the differential antennas in comparison with bistatic antennas is a high electromagnetic decoupling between the transmitting and receiving modules. The new vertical differential configuration has an additional advantage because it allows collecting GPR data reflected by layered media without any losses of information about these layers [1] and, potentially, it is a more accurate instrument for the layers thickness measurements [2]. The developed antenna system is tested in practice with the GPR at asphalt thickness measurements [3] and shown an accuracy which is better than 0.5 cm. Since this antenna system is good for sounding from above the surface (air coupled technique), the mobile laboratory was equipped with the developed GPR [3].
In order to process big set of GPR data that collected during probing at long routes of the roads, for the data processing it was tested new algorithm of the inverse problem solution. It uses a fast algorithm for calculation of electromagnetic wave diffraction by non-uniform anisotropic layers [4]. The algorithm is based on constructing a special case solution to the Riccati equation for the Cauchy problem and enables a qualitative description of the wave diffraction by the electromagnetic structure of the type within a unitary framework.
At this stage as initial data we used synthetic GPR data that were obtained as results of the FDTD simulation of the problem of UWB electromagnetic impulse diffraction on layered media. Differential and bistatic antenna configurations were tested at several different profiles of permittivity. Meanings of permittivity of each of layers were reconstructed successfully. Corresponding results are given in the presentation.

Acknowledgement
The authors acknowledge COST for funding Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar", supporting this work.

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Geophysical Research Abstracts
Vol. 18, EGU2016-16652-2, 2016
EGU General Assembly 2016

A semi-empirical model for the prediction of fouling in railway ballast using GPR

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The first step in the planning for a renewal of a railway network consists in gathering information, as effectively as possible, about the state of the railway tracks. Nowadays, this activity is mostly carried out by digging trenches at regular intervals along the whole network, to evaluate both geometrical and geotechnical properties of the railway track bed. This involves issues, mainly concerning the invasiveness of the operations, the impacts on the rail traffic, the high costs, and the low levels of significance concerning such discrete data set. Ground-penetrating radar (GPR) can represent a useful technique for overstepping these issues, as it can be directly mounted onto a train crossing the railway, and collect continuous information along the network. This study is aimed at defining an empirical model for the prediction of fouling in railway ballast, by using GPR. With this purpose, a thorough laboratory campaign was implemented within the facilities of Roma Tre University. In more details, a 1.47 m long × 1.47 m wide × 0.48 m height plexiglass framework, accounting for the domain of investigation, was laid over a perfect electric conductor, and filled up with several configuration of railway ballast and fouling material (clayey sand), thereby representing different levels of fouling. Then, the set of fouling configurations was surveyed with several GPR systems. In particular, a ground-coupled multi-channel radar (600 MHz and 1600 MHz center frequency antennas) and three air-launched radar systems (1000 MHz and 2000 MHz center frequency antennas) were employed for surveying the materials. By observing the results both in terms of time and frequency domains, interesting insights are highlighted and an empirical model, relating in particular the shape of the frequency spectrum of the signal and the percentage of fouling characterizing the surveyed material, is finally proposed.

Acknowledgement

The Authors thank COST, for funding the Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar."

Geophysical Research Abstracts
Vol. 18, EGU2016-17169-1, 2016
EGU General Assembly 2016

Recent advances in the evaluation of the strength and deformation properties of flexible pavements using GPR

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Even though there is plenty of literature contributions related to the non-destructive evaluation of road pavements using ground-penetrating radar (GPR), with several purposes spanning from the layer thicknesses evaluation to the detection of highly wet spots in the subsurface, there is still a lack of highly-reliable results concerning the mechanical assessment of road pavements, by using this technology.

This work endeavours to face this topic and proposes a semi-empirical model for predicting the elastic modulus of a flexible pavement, by employing GPR. Data were collected over three different road sections within the districts of Madrid and Guadalajara, Spain. In particular, GPR surveys were carried out at the speed of traffic over the roads N320 and N211 in the district of Gadalajara and the road N320 in the district of Madrid, for a total of 39 kilometers, approximately. In particular, air-coupled radar systems with a 1000 MHz center frequency antenna and two different 2000 MHz center frequency antennas, mounted onto an instrumented vehicle, were here employed. The calibration of the model was then performed by exploiting ground-truth data coming from other non-destructive technologies. In more details, an instrumented lorry equipped with a curviameter, namely, a deflection tool capable to collect and process continuously and in real time the mechanical response of the flexible pavement, was used in the above road sections. Promising results are here presented, and the potential of GPR for monitoring the mechanical performances of a road network is also proved.

Acknowledgement

The Authors thank COST, for funding the Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar."

Geophysical Research Abstracts
Vol. 18, EGU2016-17213, 2016
EGU General Assembly 2016

Detectability of underground electrical cables junction with a ground penetrating radar: electromagnetic simulation and experimental measurements

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For a company like Electricity De France (EDF), being able to detect accurately using non-destructive methods the position of the buried junction between two underground cables is a crucial issue. The junction is the linking part where most maintenance operations are carried out. The challenge of this work is to conduct a feasibility study to confirm or deny the relevance of Ground Penetrating Radar (GPR) to detect these buried junctions in their actual environment against clutter. Indeed, the cables are buried in inhomogeneous medium at around 80cm deep.

To do this, the study is conducted in a numerical environment. We use the 3D simulation software CST MWS to model a GPR scenario. In this simulation, we place the already optimized bowtie antennas operating in the frequency band [0.5 GHz – 3 GHz] in front of wet soil (dispersive) and dry soil where the underground cable is placed at 80cm deep.

Figure 1. The underground cable model used in the simulation scenario. The junction in the middle of the cable is represented with a diameter outgrowth.

We collect the amplitude and phase of the reflected waves in order to detect the contrast provoked by the geometric dimensions variation of the cable [1] (diameter of the cable is 48mm and the diameter of the junction 74mm). The use of an ultra-wideband antenna is necessary to reconcile resolution and penetration of electromagnetic waves in the medium to be characterized. We focus on the performance of the GPR method according to the characteristics of the surrounding medium in which the electric cables are buried, the polarization of the Tx and Rx antennas.

The experimental measurement collected in the EDF site will be presented. The measured data are processed using the clutter reduction method based on digital filtering [2]. We aim at showing that using the developed bowtie antennas that the GPR technique is well adapted for the cable junction localization even in cluttered environment.

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Geophysical Research Abstracts
Vol. 18, EGU2016-17258-1, 2016
EGU General Assembly 2016

A GPR-based simulation approach for the analysis of railway ballast

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This study aims at proposing a model capable to assess the physical conditions of railway ballast, in terms of percentage of fouling within the material, by analyzing its electromagnetic response.

For the calibration of such a model, a laboratory set-up was implemented in order to reproduce a real-scale railway environment. In more details, a 1.47 m long × 1.47 m wide × 0.48 m high plexiglass formwork was laid over a metal sheet, to define a proper domain of investigation. The formwork was then filled up with railway ballast, progressively fouled with a fine-grained pollutant material, namely, an A4 soil type according to the ASSHTO soil classification. At each step of fouling percentage, electromagnetic surveys were carried out by employing several ground-penetrating radar (GPR) systems, in both ground-coupled and air-coupled configurations.

On the other hand, the validation of the model was performed through a simulation-based approach. In particular, the main physical and geometrical properties of each ballast-pollutant configuration were reproduced by means of a random sequence absorption (RSA) approach. For the representation of the shape of the solid matrix of the ballast, a relatively complex geometry was here adopted. Finally, the developed geometries were processed by the GprMax 2D numerical simulator, employing a finite-difference time domain (FDTD) model capable of generating a synthetic GPR response for the several configurations analysed in laboratory environment.

As result, the potential of the combined use of RSA and FDTD approaches is demonstrated, and a model for characterizing such a complex coarse-grained heterogeneous material is finally proposed.

Acknowledgement

The Authors thank COST, for funding the Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar."

Geophysical Research Abstracts
Vol. 18, EGU2016-17965-1, 2016
EGU General Assembly 2016

Ground-penetrating radar investigation of St. Leonard's Crypt under the Wawel Cathedral (Cracow, Poland) - COST Action TU1208

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The Wawel ensemble, including the Royal Castle, the Wawel Cathedral and other monuments, is perched on top of the Wawel hill immediately south of the Cracow Old Town, and is by far the most important collection of buildings in Poland. St. Leonard's Crypt is located under the Wawel Cathedral of St Stanislaus BM and St Wenceslaus M. It was built in the years 1090-1117 and was the western crypt of the pre-existing Romanesque Wawel Cathedral, so-called Hermanowska. Pope John Paul II said his first Mass on the altar of St. Leonard's Crypt on November 2, 1946, one day after his priestly ordination.

The interior of the crypt is divided by eight columns into three naves with vaulted ceiling and ended with one apse. The tomb of Bishop Maurus, who died in 1118, is in the middle of the crypt under the floor; an inscription "+ MAVRVS EPC MCXVIII +" indicates the burial place and was made in 1938 after the completion of archaeological works which resulted in the discovery of this tomb. Moreover, the crypt hosts the tombs of six Polish kings and heroes: Michał Korybut Wiśniowiecki (King of the Polish-Lithuanian Commonwealth), Jan III Sobieski (King of the Polish-Lithuanian Commonwealth and Commander at the Battle of Vienna), Maria Kazimiera (Queen of the Polish-Lithuanian Commonwealth and consort to Jan III Sobieski), Józef Poniatowski (Prince of Poland and Marshal of France), Tadeusz Kościuszko (Polish general, revolutionary and a Brigadier General in the American Revolutionary War) and Władysław Sikorski (Prime Minister of the Polish Government in Exile and Commander-in-Chief of the Polish Armed Forces). The adjacent six crypts and corridors host the tombs of the other Polish kings, from Sigismund the Old to Augustus II the Strong, their families and several Polish heroes.

In May 2015, the COST (European COoperation in Science and Technology) Action TU1208 "Civil engineering applications of Ground Penetrating Radar" organised and offered a Training School (TS) on the "Applications of Ground Penetrating Radar in urban areas: the sensitive case of historical cities." The Action TU1208 is coordinated by "Roma Tre University" (Rome, Italy) and the TS was hosted by the Cracow University of Technology (Cracow, Poland). It was attended by 25 PhD students and early-career investigators coming from Albania, Belgium, Germany, Italy, Poland, Romania, Russia and Slovenia. Trainers and Trainees had the great honour and privilege to carry out practical sessions in St Leonard's Crypt, in cooperation with the companies Restauro (Toruń, Poland) and Geoservice (Athens, Greece).

Over the centuries, city centres have been continuously changing, developing and adapting to the requirements of society, architectural planning and advancing technology. Under the pressure of urbanisation, many cities and towns have significantly expanded and the limited space in their centres has been exploited more intensively. The shallow subsurface of historical cities is nowadays a very complicated scenario including reams of pipes, cables, rubble, bars and slabs of reinforced concrete, backfilled excavation trenches and pits, cellars, wells, cavities, tunnels, graves, walls and foundations of former houses, churches, monasteries, town fortifications, along with several other modern and ancient structures and manufacts. For the prospection of such a diversified, multilayered, intricate and complex underground environment, both for archaeological and civil-engineering purposes, Ground Penetrating Radar (GPR) is a very effective non-destructive geophysical method. GPR is a powerful tool not only for the prospection of subsurface but also for the non-invasive testing of historical buildings, fountains, historical bridges, sculptures, frescoes, pottery and other objects collected in museums: it can give information about their state of preservation, it can significantly help to address a restoration project properly, and sometimes it can also help to achieve information of historical interest.

The TS presented an insight into the challenges, advantages and potential of GPR prospection in historical cities. Data examples from urban historical centres were presented and discussed. An introduction to electro-

magnetic modelling of GPR was provided. To widen the perspective, the school included an introduction to urban remote sensing, describing how high-resolution satellite imagery or alternative sources of image date can be exploited for urban feature extraction, to analyse population, energy use, and other aspects of the urban environment.

In this work, data collected in St Leonard's Crypt will be presented for the first time. The activities focused on surveying the floor of the crypt, in order to obtain an image of the tomb of Bishop Maurus, verify whether further cavities were present and collect information about the subsurface of the crypt. GPR scans were taken on a 20 cm x 20 cm grid. Subsequently, an interesting area of smaller extent was chosen, where further data were collected on a 10 cm x 10 cm grid. We found out that the tomb of Bishop Maurus is shifted with respect to the inscription placed in the middle of the crypt and supposed to indicate its position. We could also detect the presence of another large cavity and estimate their size. All measurements were performed by using a CX-12 GPR pulsed system of MALA Geoscience.

Acknowledgement

The Authors are deeply grateful to the Parish of the Cathedral of St. Stanislaus BM and St. Wenceslas M, Cracow, Poland, for authorizing us to carry out the practical sessions of the Training School in St. Leonard's Crypt under the Wawel Cathedral. This was for all Trainers and Trainees a unique, touching and unforgettable experience. The Authors thank COST (www.cost.eu) for funding the Action TU1208 "Civil engineering applications of Ground Penetrating Radar" (www.GPRadar.eu) and for its constant support to the Action.

Geophysical Research Abstracts
Vol. 18, EGU2016-18097, 2016
EGU General Assembly 2016

State-of-the-art and trends of Ground-Penetrating Radar antenna arrays

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The aim of this contribution is to offer an overview on the antenna arrays for GPR systems, current trends and open issues.

Antennas are a critical hardware component of a radar system, dictating its performance in terms of capability to detect targets. Nevertheless, most of the research efforts in the Ground-Penetrating Radar (GPR) area focus on the use of this imaging technique in a plethora of different applications and on the improvement of modelling/inversion/processing techniques, whereas a limited number of studies deal with technological issues related to the design of novel systems, including the synthesis, optimisation and characterisation of advanced antennas. Even fewer are the research activities carried out to develop innovative antenna arrays.

GPR antennas operate in a strongly demanding environment and should satisfy a number of requirements, somehow unique and very different than those of conventional radar antennas. The same applies to GPR antenna arrays. The first requirement is an ultra-wide frequency band: the radar has to transmit and receive short-duration time-domain waveforms, in the order of a few nanoseconds, the time-duration of the emitted pulses being a trade-off between the desired radar resolution and penetration depth. Furthermore, GPR antennas should have a linear phase characteristic over the whole operational frequency range, predictable polarisation and gain. Due to the fact that a subsurface imaging system is essentially a short-range radar, the coupling between transmitting and receiving antennas has to be low and short in time. GPR antennas should have quick ring-down characteristics, in order to prevent masking of targets and guarantee a good resolution. The radiation patterns should ensure minimal interference with unwanted objects, usually present in the complex operational environment; to this aim, antennas should provide high directivity and concentrate the electromagnetic energy into a narrow solid angle. As GPR antennas work very close to the matter or even in contact with it, changes in electrical properties of the matter should not affect strongly the antenna performance, so that a wide applicability of the radar system can be achieved. Moreover, antennas should provide stable performance at different elevation levels. For an efficient coupling of electromagnetic waves into the ground/investigated structure, good impedance matching is necessary at the antenna/matter interface. Another important requirement concerns the weight and size of the antennas: for ease of utilisation and to allow a wide applicability, the antennas shall be light and compact.

Array of antennas can be used in GPR systems to enable a faster data collection by increasing the extension of investigated area per time unit. This can be a significant advantage in archaeological prospection, road and bridge inspection, mine detection, as well as in several other civil-engineering and geoscience applications where the collection of data requires the execution of a large number of profiles. Moreover, antenna arrays allow collecting multi-offset measurements simultaneously, thereby providing additional information for a more effective imaging and characterisation of the natural or manmade scenario under test. Two approaches are possible to GPR array design. The simplest and most common is to conceive the array as a multi-channel radar system composed of single-channel radars. Much more can be achieved, if array-design techniques are employed to synthesise the whole system. This second approach is just beginning in the GPR field and is definitely promising, as it gives the possibility to fully exploit the potentiality of arrays. Another important issue, when using GPR systems on irregular surfaces, is that the position of array elements has to be recorded during the surveys, by using suitable high-precision positioning systems. Current research activities on the design of GPR arrays are progressing in various directions, including the synthesis of arrays with a high directivity achieved by using simple elements, arrays with the capability of a steerable beam as in smart antennas, arrays composed of adaptive antennas with electronic control of characteristics to adapt to different soils and materials, and application-specific arrays.

Acknowledgement
This abstract is a contribution to COST (European COoperation in Science and Technology) Action TU1208 “Civil engineering applications of Ground Penetrating Radar” (www.GPRadar.eu). The Authors thank COST for funding the Action TU1208.

Geophysical Research Abstracts
Vol. 18, EGU2016-18111, 2016
EGU General Assembly 2016

Overview and comparative study of GPR international standards and guidelines – COST Action TU1208

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Ground Penetrating Radar (GPR) can be effectively used for non-destructive testing of composite structures and diagnostics affecting the whole life-cycle of civil engineering works. Nevertheless, few recognised international standards exist in this field and inhomogeneous recommendations are present in different countries. Moreover, the levels of knowledge, awareness and experience regarding the use of GPR in civil engineering vary strongly across different European areas. The COST Action TU1208 is working hard on leveraging these differences, by sharing and disseminating knowledge and experience, as well as by developing guidelines and protocols for a safe and effective use of GPR in civil engineering. GPR users need to know which is the best way to conduct GPR measurements and what the quality level for the results should be. The TU1208 guidelines will ensure a higher efficiency and quality of GPR services and they will constitute a scientific basis for the introduction of European Standards on the application of GPR in civil engineering. The aim of this contribution is to present an in-depth overview and critical analysis of the existing GPR international and national standards and guidelines. The main documents considered in our work are listed and briefly described in the following.

Three standards are provided by the American Society for Testing and Materials (ASTM), to guide the GPR use for subsurface investigation, evaluation of asphalt-covered concrete bridge decks, and determination of pavement-layer thickness:

1. ASTM D6432-11, Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation, ASTM International, West Conshohocken, PA, 2011, www.astm.org, DOI: 10.1520/D6432-11.
2. ASTM D6087-08, Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar, ASTM International, West Conshohocken, PA, 2008, www.astm.org, DOI: 10.1520/D6087-08.
3. ASTM D4748-10, Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar, ASTM International, West Conshohocken, PA, 2010, www.astm.org, DOI: 10.1520/D4748-10.

Further ASTM standards exist, not focused on GPR but including useful information (details are not provided here, for brevity reasons). There are no standards in Europe, instead, guiding the GPR use for subsurface prospecting and regulating the numerous applications of this non-destructive technique.

The following Radio and Telecommunications Terminal Equipment (RTTE) directive applies to GPR equipment and allows the placing of a GPR product on the European (EU) market for sale: Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999, on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity. Official Journal of the European Union, L 91, 7.4.1999, open access on ec.europa.eu. This document will be repealed, since 13 June 2016, by the following RTTE directive: Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014, on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment, repealing Directive 1999/5/EC. Official Journal of the European Union, L 153, 22.5.2014, open access on ec.europa. Although conformance to the RTTE directive allows the placing of a GPR product on the market for sale, it does not give authority for its use. In order to use the equipment, in the majority of EU member countries, a license is required. The license is controlled and issued by the radio administration in each of the member countries.

The Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) considers and develops policies on electronic communications activities in European context, taking account of European and international legislations and regulations. There are 48 European countries involved in the CEPT, which cooperate to regulate posts, radio spectrum and communications networks in Europe. The ECC agreed to the decision ECC/DEC/(06)08, specifically referred to GPR and Wall Penetrating Radar (WPR) systems: ECC Decision of 1 December 2006 on the conditions for use of the radio spectrum by Ground- and Wall- Probing Radar (GPR/WPR) imaging systems, 14 December 2006, open access on www.cept.org. This is not legally binding on member countries. It is currently implemented by 25 and partly

implemented by 2 of the 48 administrations; 5 further administration are considering and studying the decision. Outside Europe, different approaches exist, ranging from very formal technical approval and licensing conditions to no specific rules.

A series of standards and codes, introduced by the European Telecommunications Standards Institute (ETSI), regulate the GPR use and its emissions of electromagnetic radiation in Europe:

1. ETSI EN 301 489-1 v1.9.2, Electromagnetic compatibility and Radio spectrum Matters (ERM); ElectroMagnetic Compatibility (EMC) standard for radio equipment and services; Part 1: Common technical requirements, Sept. 2011, open access on www.etsi.org, Ref. DEN/ERM-EMC-230-32, 45 pp. [7]. This document is a Harmonized European Standard.
2. ETSI EN 301 489-32 v1.1.1, Electromagnetic compatibility and Radio spectrum Matters (ERM); ElectroMagnetic Compatibility (EMC) standard for radio equipment and services; Part 32: Specific conditions for Ground and Wall Probing Radar applications, Sept. 2009, open access on www.etsi.org, Ref. DEN/ERM-EMC-230-32, 12 pp. [8]. This document is currently (May 2015) a Candidate Harmonized European Standard (Telecommunication Series).
3. ETSI EN 302/066-1 v1.2.1, Electromagnetic compatibility and Radio spectrum Matters (ERM); Ground- and Wall- Probing Radar applications (GPR/WPR) imaging systems; Part 1: Technical characteristics and test methods, Dec. 2007, open access on www.etsi.org, Ref. REN/ERM-TG31A-0113-1, 25 pp. [9]. This document is a Harmonized European Standard (Telecommunications series).
4. ETSI EN 302/066-2 v1.2.1, Electromagnetic compatibility and Radio spectrum Matters (ERM); Ground- and Wall- Probing Radar applications (GPR/WPR) imaging systems; Part 2: Harmonized EN covering essential requirements of article 3.2 of the RTTE Directive, Dec. 2007, open access on www.etsi.org, Ref. REN/ERM-TG31A-0113-2, 12 pp. [10]. This document is a Harmonized European Standard (Telecommunications series).
5. ETSI EG 202 730 v1.1.1, Electromagnetic compatibility and Radio spectrum Matters (ERM); Code of Practice in respect of the control, use and application of Ground Probing Radar (GPR) and Wall Probing Radar (WPR) systems and equipment, Sept. 2009, open access on www.etsi.org, Ref. DEG/ERM-TGUWB-010, 11 pp. [11]. This document is currently (May 2015) an ETSI guide.

Few National GPR Guidelines and Standards exist in Europe. In France, the National standard NF S 70-003, Parts 1-3, is concerned with the use of GPR to detect buried utilities. Still in France, Cerema/Ifsttar produced protocols for road inspection. In Germany, the DGZfP e.V. (German Society for Non-Destructive Testing) published a fact sheet called “Merkblatt B10” on the radar method for non-destructive testing in civil engineering (2008). Still in Germany, there is a BASt (Federal Highway Administration) instruction sheet on the use of GPR to gain inventory data of road structure (2003). In Poland, the national regulation of September 24, 1998 (Dz.U. Nr 126 poz. 839) cites ‘georadar testing’ as a method to investigate the soil structure. In Scandinavia, recommendations for guidelines were developed during the MARA NORD Project (2010-2012) on the use of GPR in asphalt air voids content measurements, in road construction quality control, in bridge deck surveys, in road rehabilitation projects and in site investigations.

Acknowledgement

This work stems from the research activities of COST (European COoperation in Science and Technology) Action TU1208 “Civil engineering applications of Ground Penetrating Radar.” The Authors thank COST (www.cost.eu) for funding the Action TU1208 (www.GPRadar.eu). Part of this work was carried out during the Short-Term Scientific Mission STSM-TU1208-24656 “Comparative study of GPR international standards and guidelines” (Dr Lara Pajewski, Italy, visiting Prof Marian Marciniak, Poland).

Geophysical Research Abstracts
Vol. 18, EGU2016-18409-1, 2016
EGU General Assembly 2016

Enhancement of the migrated results with the deblurring filter

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In this paper we introduce a method that uses the deblurring filter to further improve the migrated GPR results. While applying migration to near range radar systems such as GPR, we may suffer from the imaging artifacts or low resolution due to the limited aperture size or coarsely sampled data. In order to solve this problem, least square approach can be applied.

It can be presented with the following equations:

The forward modelling can be presented as a linear calculation as (1)

$d = Lm$ (1)

The real inverse processing should be (2)

$m = L^{-1}d$ (2)

Here d is the acquired GPR data, L is the forward modelling matrix and m is the reflectivity model of the survey area. Since the inverse matrix L^{-1}

is almost impossible to determine, we normally use the simplified method that use the adjoint matrix as the estimation of the inverse matrix. And it is proved that migration is just the adjoint matrix of the forward modelling matrix. Hence the migration processing can be written as (3)

$m* = L^T d$ (3)

The analytic least square solution can be given as (4)

$m* = (L^T L + \mu I)^{-1} \quad L^T d$ (4)

The least square results give much higher resolution and most of the artifacts can be eliminated. But this method requires extremely large computation so it is not really practical.

Here we propose another approach, by combining (1) and (3) we can also get (5)

$m = (L^T L)^{-1} \quad m*$ (5)

It indicates that we may further improve the migrated results with an inverse filter $(L^T L)^{-1}$. Actually, this is known as the deblurring processing for imaging problem. This deblurring filter is still very difficult to solve for the whole imaging area, but we can use the local filters at different position instead of a whole filter. In order to realize this method, a dictionary needs to be reconstructed correspond to the antenna configuration and the background velocity first. At each local window we put a point scatter in the middle and calculate the forward modelling result and the migrated result of this local window. Then the local deblurring filter can be estimated with (5) by a matched filter. After we construct this dictionary for a certain survey area, we can apply the filters to the acquired dataset. In order to improve the imaging quality, the filters at different local windows should be overlapped properly.

We applied our method to the simulated GPR dataset which is spatially coarse sampled. The results show that the migration artifacts caused by the coarse sampling can be well eliminated and the target can be reconstructed with high resolution. The imaging feature is very similar to the least square migration result but our method do not need iteration.

Geophysical Research Abstracts
Vol. 18, EGU2016-18414-1, 2016
EGU General Assembly 2016

Moisture evaluation of wood material using GPR with WARR method - COST Action TU1208

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This work deals with the study of the sensitivity of GPR electromagnetic waves to moisture variation in wood material in relation with the direction of fibers and polarization of Electromagnetic field. The relations between relative permittivity and moisture content and the amplitude attenuation with distance was a target study using the direct waves in Wide Angle Radar Reflection (WARR) configuration. Comparison of results measured with reflected waves and direct waves was of main importance since they have different behavior in relation with moisture variation, due to different path of propagation. This research activity has been carried out during one Short-Term Scientific Missions (STSM) funded by the COST (European Cooperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" in November-December 2015.
In context of durability evaluation of construction materials, several studies have been carried out by the I2M team, University of Bordeaux, using direct and reflected waves for the evaluation of water content on concrete and wood materials [1-3]. As related to the wood material there is one study carried out using the reflected waves on wood for different humidity and different wood samples, in all the direction of polarization using GPR technique ground coupled antenna at 1.5 GHz [3]. This work continued with different moisture content in order to study the behavior of direct waves as function of moisture. Results taken from those measurements are compared with them from Fixed Offset (reflected method) with one antenna (1.5GHz or 2.6GHz), realized from the previous studies from the I2M and already published [1-3].
The results taken from this work from the reflected waves, show that the effect of wood anisotropy is significant on the variation of relative permittivity with moisture content on wood sample and that is in good agreement with the previous results [3-6]. As related to the direct waves, a small change in the dielectric constants exists between transversal and parallel directions. The dielectric constant shows values that coincide with the case of radial polarization of the EM field. This can be explained from the propagation path of direct waves. Since the EM field of direct waves, propagates in the upper part of the sample, the effect of polarization is almost the same in both directions as it is the case of radial polarization when the reflected method was used.
During future STSMs we foresee to do further experimental work with the direct wave method (WARR) on different wood samples, in order to confirm the effect of wood anisotropy and moisture content on GPR direct wave propagation.

Acknowledgement

The Authors are grateful to COST - European Cooperation in Science and Technology (www.cost.eu) for funding the Action TU1208 "Civil engineering applications of Ground Penetrating Radar" (www.GPRadar.eu). Many thanks to the I2M, University of Bordeaux, for the valuable collaboration and hospitality during this STSM.

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Geophysical Research Abstracts
Vol. 18, EGU2016-18416, 2016
EGU General Assembly 2016

Non-destructive tests for railway evaluation: Detection of fouling and joint interpretation of GPR and track geometric parameters - COST Action TU1208

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During the last years high-performance railway lines have increased both their number and capabilities. As all types of infrastructures, railways have to maintain a proper behaviour during the entire life cycle. This work is focused on the analysis of the GPR method and its capabilities to detect defects in both infra and superstructure in railways. Different GPR systems and frequency antennas (air-coupled with antennas of 1.0 and 1.8 GHz, and ground-coupled with antennas of 1.0 and 2.3 GHz) were compared to establish the best procedures.

For the assessment of the ground conditions, both GPR systems were used in combination with Falling Weight Deflectometer (FWD) load tests, in order to evaluate the bearing capacity of the subgrade. Moreover, Light Falling Weight Deflectometer (LFWD) measures were performed for the validation of the interpretation of the damaged areas identified from GPR and FWD tests. Finally, to corroborate the joint interpretation of GPR and FWD-LFWD, drill cores were extracted in the damaged areas identified based on the field data. Comparing all the data, a good agreement was obtained between the methods, when identifying both anomalous deflections and reflections. It was also demonstrated that ground-coupled systems have clear advantages compared to air-coupled systems since these antennas provide both better signal penetration and vertical resolution to detect fine details like cracking.

Regarding the assessment of the thickness, three different high-speed track infrastructure solutions were constructed in a physical model, using asphalt as subballast layer. Four different antennas were used, two ground- and two air-coupled systems. Two different methodologies were assumed to calibrate the velocity of wave propagation: coring and metal plate. Comparing the results obtained, it was observed that the ground-coupled system provided higher values of wave velocity than the air-coupled system. The velocity values were also obtained by the amplitude or metal plate method with the air-coupled system. These velocities values were similar to those values obtained with the ground-coupled system, when using the coring method.

Some laboratory tests were also developed in this work aiming to evaluate the dielectric constants for different levels of ballast fouling (0, 7.5 and 15%). The effect of the water presence on the dielectric constant was also evaluated by simulating different water contents: 5.5, 10 and 14%. Different GPR systems and configuration were used. The results have demonstrated that dielectric values increase with the increasing of fouling conditions. The dielectric constants also increase with the increasing of water content. However, the analysis of all the results obtained has revealed that values are more sensitive to the fouling level rather than to the water content variation. The dielectric constants obtained with a frequency of 1.0 GHz were slightly lower than those obtained with higher frequencies of 1.8 and 2.3 GHz. Additionally, the dielectric constants obtained for all the measurements, increasing fouling conditions and water contents, with a frequency of 1.0 GHz, were also different. Thus, the dielectric constant values obtained with the ground-coupled antenna were slightly lower than those obtained with the air-coupled antenna.

Geophysical Research Abstracts
Vol. 18, EGU2016-18417-1, 2016
EGU General Assembly 2016

Nondestructive tests for railway monitoring. European Experience in COST Action TU1208

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The railway monitoring is an important issue for a proper maintenance planning. With the increase in loads and travel speed, it is important to be able to diagnose the track defects and to plan the proper maintenance without interfering with the users. Traditionally, the maintenance actions are planned based on the geometric level parameters assessed without contact with the line, at traffic speed, by dedicated inspection vehicles. Nevertheless, the geometric condition of the line does not provide information on the defects causes. In order to complements the information on the causes, geophysics measurements can be performed in a nondestructive way. Among these later methods, Ground Penetrating Radar (GPR) is a quick and effective technique to evaluate infrastructure condition in a continuous manner, replacing or reducing the use of traditional drilling method. GPR application to railways infrastructures, during construction and monitoring phase, is relatively recent. It is based on the measuring of layers thicknesses and detection of structural changes. It also enables the assessment of materials properties that constitute the infrastructure and the evaluation of the different types of defects such as ballast pockets, fouled ballast, poor drainage, subgrade settlement and transitions problems. These deteriorations are generally the causes of vertical deviations in track geometry. Moreover, the development of new GPR systems with higher antenna frequencies, better data acquisition systems, more user friendly software and new algorithms for calculation of materials properties can lead to a regular use of GPR.

A resume of the European experience in COST Action TU1208 of the application of GPR for railway monitoring and the measurement interpretation is presented in this paper. Also complementary nondestructive tests and other geophysical methods are referred, together with case studies of their application. The main troubleshooting and the needs for data analysis tools that can improve the processing of the measurements are highlighted. Future approaches of combined application of geophysical methods, load tests and track geometry measurements are addressed. A possible methodology of joint interpretation and examples of maintenance measurements adequate to the deterioration causes are presented.

Geophysical Research Abstracts
Vol. 18, EGU2016-18427, 2016
EGU General Assembly 2016

Assessment of waterfront location in hardened concrete by GPR within COST Action TU1208

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This work focuses on the analysis of the capability of Ground-Penetrating radar (GPR) technique for evaluating how the water penetrates into concrete samples by means of the assessment of the waterfront advance. Research activities have been carried out during a Short-Term Scientific Missions (STSMs) funded by the COST (European Cooperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" in November 2015.

The evaluation of water penetrability is crucial in most building materials, such us concrete, since, water and aggressive chemical agents dissolved therein contribute to the deterioration of the material. A number of techniques have been developed to measure their advance in concrete. Although the most common method for measuring water content is the gravimetric method by observing the change in mass, this method has a large number of disadvantages. In this context, non-destructive techniques as GPR play an interesting role. In particular, the application of GPR in the building materials area is providing very promising and interesting results regarding the building materials characterization and especially concrete deterioration evaluation [1-3]. In addition, recent experimental studies highlight the strong relation between wave propagation parameters (velocity and energy level) and water content advance [4-5].

Water content has a decisive influence on dielectric properties and those might be assessed by the study of the wave properties that are derived by using GPR. Therefore, the waterfront advance will result in a change on wave parameters. In line with this, this research is focused on the development of specific processing algorithms necessary to understand how the water penetrates and how the wave parameters will be affected regarding the location of the antenna in reference to the water absorption direction. For this purpose, concrete samples were manufactured, which after curing (90 days) and oven drying were immersed into water for a certain time. Then, GPR measurements, with a 2 GHz central frequency antenna, were performed at specific time intervals, placing the antenna on the same side of the concrete samples that was immersed into water. After conducting GPR measurements, concrete samples were broken in two pieces to perform the visual analysis of the waterfront advance.

After processing the GPR records velocity increments ware calculated and analyzed. Very accurate adjustments were found between the velocity increments and the waterfront depth, regardless the wave peaks of the direct and reflected wave used to calculate velocity increments.

These results are of quite importance, because even if we are not able to locate the waterfront reflection or if it is overlapped with the direct wave signal, we might predict the waterfront position with high reliability.

Acknowledgement

The Authors are grateful to COST - European Cooperation in Science and Technology (www.cost.eu) for funding the Action TU1208 "Civil engineering applications of Ground Penetrating Radar" (www.GPRadar.eu).

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Geophysical Research Abstracts
Vol. 18, EGU2016-18428, 2016
EGU General Assembly 2016

Two-way WKB Approximation Applied to GPR

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The main goal of subsurface radio wave probing consists in reconstruction of the shape and the electrical properties of buried objects in material media. For this purpose the knowledge of the laws of EM pulse excitation and propagation in non-uniform subsurface medium is required, as well as the methods and algorithms of solving the inverse problem. Two ways of treating this problem exist. On the one hand, one can describe EM wave propagation by solving the Maxwell's equations with finite difference methods implemented in computer codes. However, when solving inverse problems, pure numerical algorithms require huge amount of calculation and, as a consequence, long calculation time. In this respect, more promising are analytical approaches. Here, we apply couple wave theory ("two-way WKB" approximation) to the problem of subsurface wave propagation. The derived formulas can be used in GPR design and for fast data processing of the experimental data.

We start from the 1D model problem of GPR probing. Classical WKB method [1] allows one to describe wave propagation through non-uniform media with slowly varying dielectric permittivity. A principal shortcoming of this approximation is that it does not take into account backward reflection from permittivity gradients. Consequently, WKB method as such can not be used for the purposes of GPR sounding. An extension of this approximation consists in solving two coupled WKB-type equations by iterations. This approach properly describes backward reflections and provides good accuracy in a wide frequency range [2]. In our previous work [3] a time-domain counterpart of the Bremmer-Brekhovkikh approximation has been derived and applied to a 1D inverse problem of subsurface medium probing by an ultra-wide band EM pulse.

In order to convert this approach into a practical GPR algorithm, a more realistic model is required: 2D or 3D propagation from a localized source with the effects of wave divergence and refraction taken into account. In this work we study bistatic EM pulse probing of a horizontally layered medium in a 2D case. Coupled WKB equations set describing both forward and backward waves are derived and solved analytically.

The comparison of our semi-analytical solutions with numerical calculations by gprMax software [4] demonstrates a good agreement, being hundreds of times faster than the letter. Our numerical results explain the protracted return pulses in the low-frequency GPR data. As an example, we discuss the experimental data obtained during the GPR mission in search of a big fragment of Chelyabinsk meteorite under a thick silt layer at the bottom of Chebarcul' Lake [5].

Acknowledgement
The Authors are grateful to the European Cooperation in Science and Technology (www.cost.eu) facilitating this work by a Short-Term Scientific Missions (STSM) within the framework of the Action TU1208 "Civil engineering applications of Ground Penetrating Radar" (www.GPRadar.eu).
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Geophysical Research Abstracts
Vol. 18, EGU2016-18490, 2016
EGU General Assembly 2016

Determining change of bathymetry with GPR method in Ordu-Giresun, a sea-filled airport in the Black Sea, Turkey

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Ordu-Giresun (OGU) is a newly-constructed airport, the first sea-filled airport in Turkey and in Europe, and the second airport in the world after Osaca-Japan. The airport is between Gulyalı district in Ordu city and Piraziz district in Giresun city in Black Sea -Turkey. A protection breakwater has been constructed by filling a rock approximately 7.435-m long and with an average height of 5.5 m. Then, the Black Sea has been filled until 1 m over the sea level, approximately the area is 1.770.000 m^2 wide and includes a runway, aprons and taxiway covered by breakwater. The runway has a 1-m thickness, 3-km length and 45-m width, PCN84 strength, and stone mastic asphalt surface. The aprons has a 240 x 110 m length and PCN110 strength, the taxiway is 250 x 24 m wide. The airport was started to be constructed in July 2011 and it began to serve on 22th May 2015.

The aim of this study was to determine the depth of the rock-filled layer and the amount of sinking of the bathymetry which has been determined before filling processing. In addition, before bathymetry determination, unconsolidated sediments had been removed from the bottom of the sea. There were four drilling points to control the sinking of the bathymetry. Therefore, six suitable Ground Penetrating Radar (GPR) profiles were measured, crossing these points with runway and aprons, using 250-MHz and 100-MHz shielded antennas.

Starting points of the profiles were in the middle of the runway to merge between depth and thickness changing of the filled layer and bathymetry along the profiles. Surface topography changing was measured spaced 1 m apart with 1 cm sensitivity on each profile. At the same time, similarly the topography changing, bathymetry coordinates was re-arranged along the each profile. Topography corrections were applied to the processed radargrams and then the bottom boundary lines of the rock-filled layer were determined. The maximum height was 3.5 m according to the sea level, which was on the middle point of the runway, representing zero depth of the radargrams of the profiles. To determine the amount of the sinking of the rock filled layer, the first sea level were lined at 3.5 m in depth on the right side depth axes of the radargrams. The second, bathymetry changing lines were placed on the interested radargrams. Finally, differences between the bottom boundary lines of the filled layer and bathymetry lines were compared. The results showed that GPR method could be applied successfully to determine the depth of the rock filled layer in Black Sea and the small amount of the sinking of the bathymetry.

Acknowledgement
This project has been supported by Cengiz - Içtaş Joint Venture-Turkey. This study is a contribution to the EU funded COST action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" (www.GPRadar.eu, www.cost.eu).

Geophysical Research Abstracts
Vol. 18, EGU2016-18494, 2016
EGU General Assembly 2016

Investigation of the Sultan Alp Arslan tomb with geophysical methods, in the historical Merv city (Turkestan)

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Sultan Alp Arslan (1029-1072) was the second Sultan of the Seljuq Empire and great-grandson of Seljuq the eponymous founder of the dynasty. Sultan Alp Arslan's victories changed the balance in near Asia completely in favour of the Seljuq Turks and Sunni Muslims. His victory at Manzikert (26 August 1071) is often cited as the beginning of the end of Byzantine power in Anatolia, and the beginning of Turkish identity in Anatolia. Sultan Alp Arslan eliminated theobstacles to the conquest of Anatolia and played a major role in making this territory a homeland for the Seljuqs. By taking the Emperor captive, Sultan Alp Arslan gained great fame but in 1072, on an expedition to Western Turkestan, he met with death in an unexpected way and at a relatively early age, in his 42nd year. There have been found different stories of the death of this great Turkish Sultan in certain sources. Unfortunately, there has not been found The Sultan's resting place until now.

This paper is concerned with the investigation of the Sultan Alp Arslan Tomb in the historical Merv (Marv) city in Turkestan, by using Ground Penetrating Radar (GPR) and gradiometer methods. The GPR and gradiometer surveys have been realized in Gavur Fortress, Sultan Fortress, Er Fortress districts and between two big Fortresses in old Merv city in selected nine study areas. We also gathered data in and around Sultan Sancar Tomb. GPR surveys were performed during January 2014 employing Ramac CU-II system equipped with a 250 MHz shielded antenna, on one meter spaced profiles. Similarly a Geoscan system was used to take magnetic data. The results of all these investigation revealed that there were possible traces for the buried tomb of the Sultan Alparslan in Gavur Kale around Cuma Mosque and around Sultan Sancar Tomb in the study region. However, the project team was changed after our study, and the new team did not excavated our determined areas.

Acknowledgement

This project has been supported by Republic of Turkey Prime Ministry Turkish Cooperation and Coordination Agency (TIKA). This study is a contribution to the EU funded COST action TU1208 "Civil Engineering Applications of Ground penetrating Radar" (www.GPRadar.eu, www.cost.eu).

Geophysical Research Abstracts
Vol. 18, EGU2016-18496, 2016
EGU General Assembly 2016

Calibration Methods for Air Coupled Antennas - COST Action TU1208

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This work focuses on the comparison of different methods for calibrating air coupled antennas: Coring, Surface Reflection Method (SRM) and Common Mid-Point (CMP) through the analysis of GPR data collected in a test site with different pavement solutions. Research activities have been carried out during a Short Term Scientific Mission (STSM) funded by the COST (European Cooperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" in December 2015.
The use of GPR in transport infrastructures represents one of the most significant advances for obtaining continuous data along the road, with the advantage of operation at traffic speed and being a non-destructive technique. Its main application has been the evaluation of layer thickness.
For the determination of layer thickness, it is necessary to know the velocity of the signal, which depends on the dielectric constant of the material, and the two-way travel time of the reflected signal that is recorded by the GPR system. The calculation of the dielectric value of the materials can be done using different approaches such as: using fixed values based on experience, laboratory determination of dielectric values, applying the SRM, performing back calculation from ground truth references such as cores and test pits, or using the CMP method.
The problem with using ground truth is that it is time consuming, labour intensive and intrusive to traffic, in addition, a drill core is not necessarily representative of the whole surveyed area. Regarding the surface reflection technique, one of the problems is that it only measures the dielectric value from the layer surface and not from the whole layer.
Recent works already started to address some of these challenges proposing new approaches for GPR layer thickness measurements using multiple antennas to calculate the average dielectric value of the asphalt layer, taking advantage of significant hardware improvements in GPR resolution and accuracy.
For this work, three experimental sections were tested with variable thickness of the asphalt layer. For each cell, two parallel survey lines were tested and two control points were defined for each profile.
Two pairs of air-coupled bistatic antennas with central frequencies of 1.0 GHz and 1.8 GHz were employed in the tests. The GPR data was acquired with both frequencies along the survey lines in a dynamic mode and also in static mode over the control points. After the GPR survey, drill cores were extracted at the control points in order to obtain real thickness data for the bituminous layer. This approach allowed obtaining the back calculation of the dielectric constant for asphalt.
For GPR calibration with the SRM, the dielectric constant was calculated comparing the amplitude from the pavement surface with the amplitude from a metal plate reflection, collected for each cell using a metal plate above the pavement surface acting as a perfect reflector of the GPR signals.
Using the CMP method, both antennas were simultaneously moved apart on either side of each control point and the velocity of propagation was calculated adjusting the hyperbolas of the reflection on the bottom of the bituminous layer. Prior to the hyperbola fitting, the start time for the GPR data was corrected based on the velocity of the waves in the air measured in the surface reflection.
The main results obtained so far and the comparison between the different calibration methods are presented in this study.

Acknowledgement
The Authors would like to thank COST for funding the Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" and supporting this STSM.

Geophysical Research Abstracts
Vol. 18, EGU2016-18501, 2016
EGU General Assembly 2016

Detection of a Misaligned Broken Pipe by Electromagnetic Interaction

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The study we are presenting concerns electromagnetic scattering of a plane wave due to the presence of a misaligned broken pipe buried in a half-space occupied by cement and by asphalt/ground, for civil-engineering applications. In order to simulate a realistic scenario, the pipe is supposed cylindrical and made of metallic or poly-vinyl chloride (PVC) material whose electromagnetic properties are known in the literature and dimensions are the most used in civil-engineering applications. We consider the longitudinal axis of the pipe running parallel to the air-cement interface. We suppose, after the break of the pipe, that the longitudinal axes of the two parts move on a plane parallel to the separation interface, in opposite directions.
The study focuses on the electromagnetic response of the scattered electric field along a line above the interface of the media considering different distances between the longitudinal axis of the tubes in two cases: PVC and metallic material. To accomplish the study, a commercially available simulator based on the Finite Element Method (FEM) is adopted and a circularly-polarized plane wave impinging normally to the interface is considered. This kind of study could be useful for monitoring the status of buried pipes using ground penetrating radar (GPR) techniques in many applications of Civil Engineering without the need to intervene destructively in the structure.

Acknowledgement
This work is a contribution to COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" (www.GPRadar.eu, www.cost.eu).

Geophysical Research Abstracts
Vol. 18, EGU2016-18503, 2016
EGU General Assembly 2016

Use of GPR and standard geophysical methods to explore the subsurface: Example from the Maltese Archipelago

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The aim of this work is to illustrate the results of Ground Penetrating Radar (GPR) and passive seismic measurements in selected sites in Malta. The data were gathered during a Short-Term Scientific Mission (STSM) performed under the COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar." The purpose of the measures has been twofold, namely to test the performances of an innovative GPR system, recently upgraded, and to perform GPR and passive seismic analyses in several sites of interest in Malta, in order to get an insight about their geological conditions as well as about the internal status of some historical monuments.
The exploited GPR system was a prototypal stepped-frequency reconfigurable GPR, implemented by IBAM-CNR together with the University of Florence and the IDS Corporation within the research project AITECH (www.aitechnet.com/ibam.html). This system contains three equivalent couples of antennas with the same gap, achieved from two series of switches along the arms. The on and off state of the switches make equivalently longer or shorter the antennas, so to achieve efficient transmission on three bands that cover the comprehensive frequency range from 50 MHz to 1 GHz. Passive seismic techniques where used in order to gather useful data to be compared and integrated with those obtained with the GPR. Ambient noise was recorded using a three-component seismometer.
Data were gathered at the following sites a) on a cliff area close to the Golden Bay tower; b) Madliena tower; c) Laferla Cross; d) santa Maria Church. We were able to locate and determine fractures on the cliff area as well as to locate graves and buried structures at the investigated sites.

Acknowledgement
The Authors are grateful to COST - European COoperation in Science and Technology (www.cost.eu) for funding the Action TU1208 "Civil engineering applications of Ground Penetrating Radar" (www.GPRadar.eu).

Geophysical Research Abstracts
Vol. 18, EGU2016-18505, 2016
EGU General Assembly 2016

Improving GPR Surveys Productivity by Array Technology and Fully Automated Processing

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The realization of network infrastructures with lower environmental impact and the tendency to use digging technologies less invasive in terms of time and space of road occupation and restoration play a key-role in the development of communication networks.

However, pre-existing buried utilities must be detected and located in the subsurface, to exploit the high productivity of modern digging apparatus. According to SUE quality level B+ both position and depth of subsurface utilities must be accurately estimated, demanding for 3D GPR surveys. In fact, the advantages of 3D GPR acquisitions (obtained either by multiple 2D recordings or by an antenna array) versus 2D acquisitions are well-known. Nonetheless, the amount of acquired data for such 3D acquisitions does not usually allow to complete processing and interpretation directly in field and in real-time, thus limiting the overall efficiency of the GPR acquisition.

As an example, the "low impact mini-trench "technique (addressed in ITU – International Telecommunication Union - L.83 recommendation) requires that non-destructive mapping of buried services enhances its productivity to match the improvements of new digging equipment.

Nowadays multi-antenna and multi-pass GPR acquisitions demand for new processing techniques that can obtain high quality subsurface images, taking full advantage of 3D data: the development of a fully automated and real-time 3D GPR processing system plays a key-role in overall optical network deployment profitability. Furthermore, currently available computing power suggests the feasibility of processing schemes that incorporate better focusing algorithms.

A novel processing scheme, whose goal is the automated processing and detection of buried targets that can be applied in real-time to 3D GPR array systems, has been developed and fruitfully tested with two different GPR arrays (16 antennas, 900 MHz central frequency, and 34 antennas, 600 MHz central frequency). The proposed processing scheme take advantage of 3D data multiplicity by continuous real time data focusing.

Pre-stack reflection angle gathers $\boldsymbol{G}(\mathbf{x}, \theta; v)$ are computed at n_v different velocities (by the mean of Kirchhoff depth-migration kernels, that can naturally cope with any acquisition pattern and handle irregular sampling issues). It must be noted that the analysis of pre-stack reflection angle gathers plays a key-role in automated detection: targets are identified and the best local propagation velocities are recovered through a correlation estimate computed for all the n_v reflection angle gathers. Indeed, the data redundancy of 3D GPR acquisitions highly improves the proposed automatic detection reliability. The goal of real-time automated processing has been pursued without the need of specific high performance processing hardware (a simple laptop is required). Moreover, the automatization of the entire surveying process allows to obtain high quality and repeatable results without the need of skilled interpreters.

The proposed acquisition procedure has been extensively tested: more than 100 Km of acquired data prove the feasibility of the proposed approach.

Geophysical Research Abstracts
Vol. 18, EGU2016-18507, 2016
EGU General Assembly 2016

Numerical modelling of GPR ground-matching enhancement by a chirped multilayer structure - output of cooperation within COST Action TU1208

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As is well know, Ground Penetrating Radar (GPR) is an electromagnetic technique for the detection and imaging of buried objects, with resolution ranging from centimeters to few meters [1, 2]. Though this technique is mature enough and different types of GPR devices are already in use, some problems are still waiting for their solution [3]. One of them is to achieve a better matching of transmitting GPR antenna to the ground, that will increase the signal penetration depth and the signal/noise ratio at the receiving end.
In the current work, a full-wave electromagnetic modelling of the interaction of a plane wave with a chirped multilayered structure on the ground is performed, via numerical simulation. The method of single expression is used, which is a suitable technique for multi-boundary problems solution [4, 5]. The considered multilayer consists of two different dielectric slabs of low and high permittivity, where the highest value of permittivity doesn't exceed the permittivity of the ground. The losses in the ground are suitably taken into account.
Two types of multilayers are analysed. Numerical results are obtained for the reflectance from the structure, as well as for the distributions of electric field components and power flow density in both the considered structures and the ground. The obtained results indicate that, for a better matching with the ground, the layer closer to the ground should be the high-permittivity one.

Acknowledgement
This work benefited from networking activities carried out within the EU funded COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" (www.GPRadar.eu, www.cost.eu). Part of this work was developed during the Short-Term Scientific Mission COST-STSM-TU1208-25016, carried out by Prof. Baghdasaryan in the National Institute of Telecommunications in Warsaw, Poland.

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Geophysical Research Abstracts
Vol. 18, EGU2016-18513, 2016
EGU General Assembly 2016

Safety in GPR prospecting: a rarely-considered issue

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Safety issues (of people first of all, but also of the equipment and environment) are rarely considered in Ground-Penetrating Radar (GPR) prospecting and, more in general, in near-surface geophysical prospecting. As is right and fully understandable, the scientific community devotes greatest attention first of all to the theoretical and practical aspects of GPR technique, affecting the quality of attainable results, secondly to the efforts and costs needed to achieve them [1-2]. However, the (luckily) growing GPR market and range of applications make it worth giving serious consideration to safety issues, too.

The existing manuals dealing with safety in geophysics are mainly concerned with applications requiring “deep” geophysical prospecting, for example the search for oilfields and other hydrocarbon resources [3]. Near-surface geophysics involves less dangers than deep geophysics, of course. Nevertheless, several accidents have already happened during GPR experimental campaigns. We have personally had critical experiences and collected reliable testimonies concerning occurred problems as mountain sicks, fractures of legs, stomach problems, allergic reactions, encounters with potentially-dangerous animals, and more. We have also noticed that much more attention is usually paid to safety issues during indoor experimental activities (in laboratory), rather than during outdoor fieldworks. For example, the Italian National research Council is conventioned with safety experts who hold periodical seminaries about safety aspects. Having taken part to some of them, to our experience we have never heard a “lecture” devoted to outdoor prospecting.

Nowadays, any aspects associated to the use of the technologies should be considered. The increasing sensibility and sense of responsibility towards environmental matters impose GPR end-users to be careful not to damage the environment and also the cultural heritage. Near-surface prospecting should not compromise the flora and fauna (for example, the nesting of several species of birds should not be disturbed). No blaze should be caused or facilitated, no polluting substances should be improperly left in situ, no artworks should be damaged.

Last but not least, the prospectors have to be protected (as far as possible) against injuries of their goods and work. For example, the safety of the equipment has to be ensured: in our experience things not always work as expected and instruments can get easily damaged. Advices related to the transportation of equipment are worth to be given.

On the basis of these considerations, the COST (European COoperation in Science and Technology) Action TU1208 "Civil engineering applications of Ground Penetrating Radar" has undertaken the effort to prepare and issue a book on these topics [4], entitled "Recommendations for the Safety of People and Instruments in Ground-Penetrating Radar and Near-Surface Geophysical Prospecting." Several experts from all over the world contributed to the preparation of this volume, including Action’s Members and other specialists. The book has been published by the European Association of Geophysicists and Engineers (EAGE) in 2015.

The aim of this contribution is to present, disseminate and discuss, during the GI3.1 Session of the 2016 European Geosciences Union General Assembly, the most significant and interesting topics dealt within [4].

Acknowledgement

This work has benefited from the networking activities of COST Action TU1208 "Civil engineering applications of Ground Penetrating Radar" (www.GPRadar.eu, www.cost.eu). The Authors wish to thank COST for funding the Action TU1208.

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Geophysical Research Abstracts
Vol. 18, EGU2016-18517, 2016
EGU General Assembly 2016

COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar": ongoing research activities and third-year results

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This work aims at disseminating the ongoing research activities and third-year results of the COST (European COoperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar." About 350 experts are participating to the Action, from 28 COST Countries (Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Malta, Macedonia, The Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom), and from Albania, Armenia, Australia, Colombia, Egypt, Hong Kong, Jordan, Israel, Philippines, Russia, Rwanda, Ukraine, and United States of America. In September 2014, TU1208 has been recognised among the running Actions as "COST Success Story" ("The Cities of Tomorrow: The Challenges of Horizon 2020," September 17-19, 2014, Torino, IT - A COST strategic workshop on the development and needs of the European cities).

The principal goal of the COST Action TU1208 is to exchange and increase scientific-technical knowledge and experience of GPR techniques in civil engineering, whilst simultaneously promoting throughout Europe the effective use of this safe and non-destructive technique in the monitoring of infrastructures and structures.

Moreover, the Action is oriented to the following specific objectives and expected deliverables: (i) coordinating European scientists to highlight problems, merits and limits of current GPR systems; (ii) developing innovative protocols and guidelines, which will be published in a handbook and constitute a basis for European standards, for an effective GPR application in civil- engineering tasks; safety, economic and financial criteria will be integrated within the protocols; (iii) integrating competences for the improvement and merging of electromagnetic scattering techniques and of data- processing techniques; this will lead to a novel freeware tool for the localization of buried objects, shape-reconstruction and estimation of geophysical parameters useful for civil engineering needs; (iv) networking for the design, realization and optimization of innovative GPR equipment; (v) comparing GPR with different NDT techniques, such as ultrasonic, radiographic, liquid-penetrant, magnetic-particle, acoustic-emission and eddy-current testing; (vi) comparing GPR technology and methodology used in civil engineering with those used in other fields; (vii) promotion of a more widespread, advanced and efficient use of GPR in civil engineering; and (viii) organization of a high-level modular training program for GPR European users.

Four Working Groups (WGs) carry out the research activities. WG 1 focuses on the design of innovative GPR equipment, on the building of prototypes and on the testing and optimisation of new systems. WG 2 focuses on the GPR surveying of pavement, bridges, tunnels and buildings, as well as on the sensing of underground utilities and voids. WG 3 deals with the development of electromagnetic forward and inverse scattering methods, for the characterization of GPR scenarios, as well as with data-processing algorithms for the elaboration of the data collected during GPR surveys. WG 4 works on the use of GPR in fields different from the civil engineering, as well as on the integration of GPR with other non-destructive testing techniques. Each WG includes several Projects.

COST Action TU1208 is active through a range of networking tools: meetings, workshops, conferences, training schools, short-term scientific missions, dissemination activities. For more information on COST Action TU1208, please visit www.GPRadar.eu and www.cost.eu.

Acknowledgement

The Authors wish to thank COST, for funding the COST Action TU1208 "Civil engineering applications of Ground Penetrating Radar."