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Integration of modern remote sensing technologies for faster utility mapping and data extraction

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Analysis of the application of modern remote sensing technologies in current research shows a significant increase in interest in fast and efficient detection of underground installations. The most important reasons of the said application are preventing damage during excavation works, as well as the formation of the cadastre of underground utilities suitable for operating and maintaining of such resources. Given the wide area of application in the detection of underground installations, ground penetrating radar scanning technology (GPR), in this instance, is used as prevalent method for the purpose of the acquisition radargram of pipelines and the comparison with the results of the acquisition of Unmanned Aerial Vehicle - UAV drone Aibot X6 equipped with Optris PI Lightweight Kit (which consists of a miniaturized lightweight PC and a weight-optimized PI450 Optris LW infrared camera).
The aim of the research presented in the this paper is to analyze the benefits of integrating a mobile system capable of very fast, reliable and relatively inexpensive detection of heating pipelines using thermal imaging aerial inspection and GPR technology for control sampling of radargrams on specific locations of routes in order to achieve following: a simple identification of the characteristics of heating pipelines, prevention and registration of damage, as well as automated data extraction. The results of integrated application of the above-mentioned remote sensing technologies have shown that, within 10min of planned flight, it is possible to detect and georeference routes of heating pipelines in the area of 50.000m2 by application of thermal imaging inspection that assigns an adequate temperature value to each pixel in an image. The experiment showed that the registration is also possible in the case of pre-insulated and conventionally insulated heating pipes, and the difference in temperature measurements above the routes and the environment was up to 4 degrees. It should be noted that it is necessary to perform imaging in the working period, which is when the water is heated in the heating pipelines. Analysis of the efficiently defined heating pipeline routes defined by using thermal imaging inspection shows the point of temperature anomalies where it is necessary to perform control measurements using GPR technology. The control radargrams are further interpreted by applying realized automatic identification strategies software. Since the heating pipes are characterized by a distinctive method of installation (two pipes within or without concrete channels), they form a characteristic reflection in radargram, from which it is possible to identify the dimensions of the heating pipes. The dimensions of heating pipes are determined either based on estimation of standard dimensions of a concrete channel of heating pipes or based on hyperbolic reflections of the two pipes.
The research results show that by using integrated application of the above-mentioned technologies it is possible to achieve efficient and high-quality inspection of heating pipeline system with estimation of the most relevant parameters.

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Microwave sensing of tree trunks

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The main subject of this research is the observation of the inner part of living tree trunks using ground-penetrating radar (GPR). Trees are everyday part of human life and therefore it is important to pay attention to the tree conditions. The most obvious consequence of the poor tree condition is dead or injury caused by falling tree.

The trunk internal structure is divided into three main parts: heartwood, sapwood and bark, which make this medium highly anisotropic and heterogeneous. Furthermore, the properties of the wood are not only specie-dependent but also depend on genetic and on environmental conditions. In urban areas the main problem for the stability of the trees relies in the apparition of decays provoked by fungi, insect or birds. This results in cavities or decreasing of the support capacity of the tree.

GPR has proved itself to be a very powerful electromagnetic tool for non-destructive detection of buried objects. Since the beginning of the 20th century it has been used in several different areas (archaeology, landmine detection, civil engineering, ...). GPR uses the principle of the scattering of the electromagnetic waves that are radiated from a transmitting antenna. Then the waves propagate through the medium and are reflected from the object and then they are received by a receiving antenna. The velocity of the scattered signal is determined primarily by the permittivity of the material.

The optimal functionality of the GPR was investigated using the numerical simulation tool gprMax2D. This tool is based on a Finite-Difference Time-Domain (FDTD) numerical model. Subsequently, the GPR functionality was tested using the laboratory model of a decayed tree trunk. Afterwards, the results and lessons learnt in the simplified tests will be used in the processing of the real data and will help to achieve deeper understanding of them.

The laboratory model of the tree trunk was made by plastic or carton pipes and filled by sand. Space inside the model was divided into three sections to separate parts with different moisture (heartwood and sapwood) or empty space (decays).

For easier manipulation with the antenna we developed a special ruler for measuring the distance along the scans. Instead of the surveying wheel we read the distance with a camera, which was fixed on the antenna and focused on the ruler with a binary pattern. Hence, during whole measurement and the data processing we were able to identify an accurate position on the tree in view of the scan.

Some preliminary measurements on the trees were also conducted. They were performed using a GSSI 900 MHz antenna. Several tree species (beech, horse-chestnut, birch, ...) in Louvain-la-Neuve and Brussels, Belgium, have been investigated to see the internal structure of the tree decays. The measurements were carried out mainly by circumferential measurement around the trunk and also by vertical measurement along the trunk for approximate detection of the cavity. The comparison between the numerical simulations, simplified tree trunk model and real data from trees is presented.

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Assessment of highway pavements using GPR

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Highway infrastructure is a prerequisite for a functioning economy and social life. Highways, often prone to congestion and disruption, are one of the aspects of a modern transport network that require maximum efficiency if an integrated transport network, and sustainable mobility, is to be achieved. Assessing the condition of highway structures, to plan subsequent maintenance, is essential to allow the long-term functioning of a road network. Optimizing the methods used for such assessment will lead to better information being obtained about the road and underlying ground conditions. The condition of highway structures will be affected by a number of factors, including the properties of the highway pavement, the supporting sub-base and the subgrade (natural ground), and the ability to obtain good information about the entire road structure, from pavement to subgrade, allows appropriate maintenance programs to be planned.

The maintenance of highway pavements causes considerable cost and in many cases obstruction to traffic flow. In this situation, methods that provide information on the present condition of pavement structure non-destructively and economically are of great interest. It has been shown that Ground-Penetrating-Radar (GPR), which is a Non Destructive Technique (NDT), can deliver information that is useful for the planning of pavement maintenance activities. More specifically GPR is used by pavement engineers in order to determine physical properties and characteristics of the pavement structure, information that is valuable for the assessment of pavement condition.

This work gives an overview on the practical application of GPR using examples from highway asphalt pavements monitoring. The presented individual applications of GPR pavement diagnostics concern structure homogeneity, thickness of pavement layers, dielectric properties of asphalt materials etc. It is worthwhile mentioning that a number of applications are standard procedures, either separately or in combination with other NDT methods, but even for them there is still a room for improvement and there is still need to set stricter regulations Comparisons between radar results and ground truth data produce evidence in support of the statement that the accuracy and reliability of radar results is sufficient for facing many issues related to the evaluation of asphalt pavements. Thus, benefits and limits of this method are shown and recommendations for GPR inspections are presented.

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Application of Common Mid-Point Method to Estimate Asphalt

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3-D radar is a multi-array stepped-frequency ground penetration radar (GPR) that can measure at a very close sampling interval in both in-line and cross-line directions. Constructing asphalt layers in accordance with specified thicknesses is crucial for pavement structure capacity and pavement performance. Common mid-point method (CMP) is a multi-offset measurement method that can improve the accuracy of the asphalt layer thickness estimation. In this study, the viability of using 3-D radar to predict asphalt concrete pavement thickness with an extended CMP method was investigated. GPR signals were collected on asphalt pavements with various thicknesses. Time domain resolution of the 3-D radar was improved by applying zero-padding technique in the frequency domain. The performance of the 3-D radar was then compared to that of the air-coupled horn antenna. The study concluded that 3-D radar can be used to predict asphalt layer thickness using CMP method accurately when the layer thickness is larger than 0.13m. The lack of time domain resolution of 3-D radar can be solved by frequency zero-padding.

Keywords: asphalt pavement thickness, 3-D Radar, stepped-frequency, common mid-point method, zero padding.

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GPR measurements and estimation for road subgrade damage caused by neighboring train vibration load

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Generally, road can be simplified as a three-layer structure, including subgrade, subbase and pavement. Subgrade is the native material underneath a constructed road. It is commonly compacted before the road construction, and sometimes stabilized by the addition of asphalt, lime or other modifiers. As the mainly supporting structure, subgrade damage would lead in pavement settlement, displacement and crack. Assessment and monitoring of the subgrade condition currently involves trial pitting and subgrade sampling. However there is a practical limit on spatial density at which trail pits and cores can be taken. Ground penetrating radar (GPR) has been widely used to characterize highway pavement profiling, concrete structure inspection and railroad track ballast estimation. GPR can improve the economics of road maintenance.

Long-term train vibration load might seriously influence the stability of the subgrade of neighboring road. Pavement settlement and obvious cracks have been found at a municipal road cross-under a railway with culvert box method. GPR test was conducted to estimate the subgrade and soil within 2.0 m depth for the further road maintenance. Two survey lines were designed in each lane, and total 12 GPR sections have been implemented. Considering both the penetrating range and the resolution, a antenna with a 500 MHz central frequency was chosen for on-site GPR data collection. For data acquisition, we used the default operating environment and scanning parameters for the RAMAC system: 60kHz transmission rate, 50 ns time window, 1024 samples per scan and 0.1 m step-size. Continuous operation was used; the antenna was placed on the road surface and slowly moved along the road.

The strong surrounding disturbance related to railroad and attachments, might decrease the reliability of interpretation results. Some routine process methods (including the background removing, filtering) have been applied to suppress the background noise. Additionally, attribute analysis is an important tool that focused on the multi-properties of the signal. Here, cross-correlation attribute analysis has been applied for GPR profile interpretation. It compares one trace with surrounding traces to determine degrees of similar, and improves the difference between the reflected wave from detection target and its surrounding mediums, which makes it easy to detect the anomaly that couldn't be found in original GPR time profile. It's possible to identify sections of subgrade in good or worse condition, which may require specific maintenance or trail pitting investigation.

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Automated Ground Penetrating Radar hyperbola detection in complex environment

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Ground Penetrating Radar (GPR) systems are commonly used in many applications to detect, amongst others, buried targets (various types of pipes, landmines, tree roots ...), which, in a cross-section, present theoretically a particular hyperbolic-shaped signature resulting from the antenna radiation pattern. Considering the large quantity of information we can acquire during a field campaign, a manual detection of these hyperbolas is barely possible, therefore we have a real need to have at our disposal a quick and automated detection of these hyperbolas. However, this task may reveal itself laborious in real field data because these hyperbolas are often ill-shaped due to the heterogeneity of the medium and to instrumentation clutter.
We propose a new detection algorithm for well- and ill-shaped GPR reflection hyperbolas especially developed for complex field data. This algorithm is based on human recognition pattern to emulate human expertise to identify the hyperbolas apexes. The main principle relies in a fitting process of the GPR image edge dots detected with Canny filter to analytical hyperbolas, considering the object as a punctual disturbance with a physical constraint of the parameters. A long phase of observation of a large number of ill-shaped hyperbolas in various complex media led to the definition of smart criteria characterizing the hyperbolic shape and to the choice of accepted value ranges acceptable for an edge dot to correspond to the apex of a specific hyperbola. These values were defined to fit the ambiguity zone for the human brain and present the particularity of being functional in most heterogeneous media. Furthermore, the irregularity is particularly taken into account by defining a buffer zone around the theoretical hyperbola in which the edge dots need to be encountered to belong to this specific hyperbola.
First, the method was tested in laboratory conditions over tree roots and over PVC pipes with both time- and frequency-domain radars used on-ground. Second, we investigated the efficiency of this method for field data taken with a time-domain system connected to 400 and 900 MHz antennas in a forest environment. For all the tests explained above, the computational time is around 56 s for 10000 edge dots detected in a b-scan for the 900 MHz antenna and 228 s for the 400 MHz antenna. This value depends on the complexity of the images. For the given examples, the rate of non-detection is negligible and the rate of false alarms varies from 0 to 8.3% , although it is worth noting that these performance rates become difficult to evaluate for reflections that are ambiguous for our own eyes. Finally, we conducted a sensitivity analysis showing that all these criteria are needed and sufficient for a correct detection. In conclusion, the low computational time and its considerations to take into account the hyperbola irregularities make the proposed algorithm very suitable and robust for complex environments. The false alarms are easily removed by studying the continuity of the reflections between consecutive transects for linear targets such as pipes.

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GPR Application for Road Management System in Slovakia

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Road Management System in Slovakia was established in 1996. Data for database are collected from Falling Weight Deflectometer, Skiddometer and Profilograph from 25 separated sections with average length of 30 km on yearly basis. The focus is especially on roads that have been built before the year 1996.

In September 2014 the Slovak Road Administration announced the new project task which involved additional data request such as structure thicknesses, application to determine the thicknesses of bound layers and base layers, rutting analysis, transverse and longitudinal roughness and cross fall, ditch depths, the road width and pavement width. The request for data processing included the interpretation of the data in graphical display.
The requested delivery of the final project data was in December 2014.

The presentation summarizes the experiences and results of the data collection methods and technologies, data processing and evaluation methods and finally presenting the results. Also key new finding will be presented.

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Comparison of air-launched and ground-coupled configurations of SFCW GPR in time, frequency and wavelet domain

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A stepped frequency continuous wave (SFCW) ground penetrating radar (GPR) system produces waveforms consisting of a sequence of sine waves with linearly increasing frequency. By adopting a wide frequency bandwidth, SFCW GPR systems offer an optimal resolution at each achievable measurement depth. Furthermore, these systems anticipate an improved penetration depth and signal-to-noise ratio (SNR) as compared to time-domain impulse GPRs, because energy is focused in one single frequency at a time and the phase and amplitude of the reflected signal is recorded for each discrete frequency step. However, the search for the optimal practical implementation of SFCW GPR technology to fulfil these theoretical advantages is still ongoing.
In this study we compare the performance of a SFCW GPR system for air-launched and ground-coupled antenna configurations. The first is represented by a 3d-Radar Geoscope GS3F system operated with a V1213 antenna array. This array contains 7 transmitting and 7 receiving antennae resulting in 13 measurement channels at a spacing of 0.075 m and providing a total scan width of 0.975 m. The ground-coupled configuration is represented by 3d-Radar's latest-generation SFCW system, GeoScope Mk IV, operated with a DXG1212 antenna array. With 6 transmitting and 5 receiving antennae this array provides 12 measurement channels and an effective scan width of 0.9 m. Both systems were tested on several sites representative of various application environments, including a test site with different road specimens (Belgian Road Research Centre) and two test areas in different agricultural fields in Flanders, Belgium. For each test, data acquisition was performed using the full available frequency bandwidth of the systems (50 to 3000 MHz). Other acquisition parameters such as the frequency step and dwell time were varied in different tests. Analyzing the data of the different tests in time, frequency and wavelet domain allows to evaluate different performance aspects of the air-launched and ground-coupled configurations such as acquisition speed, measurement resolution, SNR and penetration depth. Based on this analysis, we highlight the advantages and disadvantages of the different SFCW GPR configurations in different application environments.

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GPR Activities in Italy: a Review

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Ground-penetrating radar has been increasingly played an important role over the last 15 years in Italy due to its high reliability in assisting the assessment of the built environment for civil engineering purposes, and in being used for geophysical investigations within many other fields of application. In line with this, original works involving fundamental aspects of this technique and implementing its use more practically in a number of interesting projects have been developed over years, both under a research and an enterprise point of view. This paper will endeavour to review the current status of ground-penetrating radar activities in Italy. Efforts have been devoted to single out the most interesting national research projects, both recent and ongoing, involving ground-penetrating radar in Italy, such as the ARCHEO project in the 90s, funded by the Italian Ministry for Universities, wherein a stepped frequency ultra-wide band radar suited for archaeological surveys was manufactured. In this framework, it is worth citing another important and more recent project, European Community funded, namely, ORFEUS, which started in the late 2006 with the overall aim of providing the capability to locate buried infrastructure accurately and reliably by means of a bore-head ground-penetrating radar for horizontal directional drilling. A review on the main use of this non-destructive technique in management activities of national resources and infrastructures has been also performed, ranging from the applications made by Anas S.p.A., i.e. the main management authority for the Italian road and motorway network, up to private enterprises specialized in both services providing and ground-penetrating radar manufacturing such as, to cite a few, Sineco S.p.A. and IDS Ingegneria dei Sistemi S.p.A., respectively. Current national guidelines, rules or protocols to be followed during radar surveys have been also reviewed. Unlike well-established international standards such as the ASTM D 4748-98 and the ASTM D 6432-99 dealing with, respectively, thicknesses evaluation of bound layers in road pavements, and equipment, field procedures and data-interpretation for the electromagnetic evaluation of subsurface materials, it has to be noted that the Italian body of laws and rules tackles the ground-penetrating radar applications under an indirect and partial approach. Despite of such situation, national guidelines concerning utilities-detection activities as well as other theoretical and practical guidelines established by the major Italian private enterprises on this field can be also considered highly relevant. Moreover, a further focus on the activities and main devices of the major Italian ground-penetrating radar manufacturers have been thoroughly described. Under a research and innovation perspective, the most important test sites, such as the site of the University of Salento to reconstruct archaeological and urban subsurface scenarios have been listed along with the main advances reached in integrating ground-penetrating radar with other non-destructive techniques, to inform and potentially improve the possibility of new developments and collaborations.

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GPR technique as a tool for decision-making regarding timber beam inner reinforcement: The Lonja de la Seda de Valencia, Spain

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This paper describes the decision-making process for the timber beam inner reinforcement of the building The Lonja de la Seda de Valencia (15th c.), Spain. This research was based on the study of 13 timber beams for their diagnosis and the characterization before decision-making in structural reinforcement. For this purpose, we integrated the results of analysis of historical documentation, in situ visual inspection and ground penetrating radar (GPR).

The rehabilitation project considered the substitution of the upper-storey floor (The Consulate of the Sea Hall) for another one that complied with the original. This room was closed due to the instability of the timber beams. For the flooring renovation it was necessary to increase the rigidity of the timber floor framing.

Preliminary conclusions, which derived from the historical documentation and in situ visual inspection of the timber coffered ceiling were: (a) timber beams supported inside masonry walls could suffer moisture and xylophage attacks, (b) timber beams were significantly damaged (splits, ring shakes, failure of beam section that reduced its bearing capacity), (c) substantial timber beam warping.

So the main objectives of this GPR study were: to detect splits, to identify failure of section due to biological attacks, to pinpoint epoxy resin reconstructions and to assess the severity of the damages observed on surface.

A GPR survey was carried out in timber coffered-ceiling beams of The Consulate of the Sea Hall. Radar measurements were carried out using a SIR-10H system (GSSI) and a 1.6 GHz ground coupled antenna, due to the timber beam dimensions (0.45 x 0.45 x 8.75 m. A total of 37 longitudinal profiles were collected in the centre of all the beam accessible sides. After radragram processing steps, a number of anomalies were detected in the records, which were analysed. The outcomes derived from this GPR study were taken into account when it came to make decisions in the final restoration project of the timber coffered ceiling elements: timber beams, wooden latticework and floor.

The results obtained in this survey are a good example of GPR application in Civil Engineering for timber beam inner reinforcement of a building, establishing technical criteria.

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Inferring strength and deformation properties of hot mix asphalt layers from the GPR signal: recent advances

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The great flexibility of ground-penetrating radar has led to consider worldwide this instrument as an effective and efficient geophysical tool in several fields of application. As far as pavement engineering is concerned, ground-penetrating radar is employed in a wide range of applications, including physical and geometrical evaluation of road pavements. Conversely, the mechanical characterization of pavements is generally inferred through traditional (e.g., plate bearing test method) or advanced non-destructive techniques (e.g., falling weight deflectometer). Nevertheless, measurements performed using these methods, inevitably turn out to be both much more time-consuming and low-significant whether compared with ground-penetrating radar's potentials. In such a framework, a mechanical evaluation directly coming from electromagnetic inspections could represent a real breakthrough in the field of road assets management. With this purpose, a ground-penetrating radar system with 600 MHz and 1600 MHz center frequencies of investigation and ground-coupled antennas was employed to survey a 4m×30m flexible pavement test site. The test area was marked by a regular grid mesh of 836 nodes, respectively spaced by a distance of 0.40 m alongside the horizontal and vertical axes. At each node, the elastic modulus was measured using a light falling weight deflectometer. Data processing has provided to reconstruct a 3-D matrix of amplitudes for the surveyed area, considering a depth of around 300 mm, in accord to the influence domain of the light falling weight deflectometer. On the other hand, deflectometric data were employed for both calibration and validation of a semi-empirical model by relating the amplitude of signal reflections through the media along fixed depths within the depth domain considered, and the Young's modulus of the pavement at the evaluated point. This statistically-based model is aimed at continuously taking into account alongside the depth of investigation, of both the different strength provision of each layer composing the hot mix asphalt pavement structure, and of the attenuation occurring to electromagnetic waves during their in-depth propagation. Promising results are achieved by matching modelled and measured elastic modulus data. This continuous statistically-based model enables to consider the whole set of information related to each single depth, in order to provide a more comprehensive prediction of the strength and deformation behavior of such a complex multi-layered medium. Amongst some further developments to be tackled in the near future, a model improvement could be reached through laboratory activities under controlled conditions and by adopting several frequency bandwidths suited for purposes. In addition, the perspective to compare electromagnetic data with mechanical measurements retrieved continuously, i.e. by means of specifically equipped lorries, could pave the way to considerable enhancements in this field of research.

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Assessment of in-situ compaction degree of HMA pavement surface layers using GPR and novel dielectric properties-based algorithms

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Field compaction of asphalt pavements is ultimately conducted to achieve layer(s) with suitable mechanical stability. However, the achieved degree of compaction has a significant influence on the performance of asphalt pavements. Providing all desirable mixture design characteristics without adequate compaction could lead to premature permanent deformation, excessive aging, and moisture damage; these distresses reduce the useful life of asphalt pavements. Hence, proper construction of an asphalt pavement is necessary to develop a long lasting roadway that will help minimize future maintenance. This goal is achieved by verifying and confirming that design specifications, in this case density specifications are met through the use of Quality Assurance (QA) practices.

With respect to in-situ compaction degree of hot mix asphalt (HMA) pavement surface layers, nearly all agencies specify either cored samples or nuclear/ non nuclear density gauges to provide density measurement of the constructed pavement. Typically, a small number of spot tests (with either cores or nuclear gauges) are run and a judgment about the density level of the entire roadway is made based on the results of this spot testing. Unfortunately, density measurement from a small number of spots may not be representative of the density of the pavement mat. Hence, full coverage evaluation of compaction quality of the pavement mat is needed.

The Ground Penetrating Radar (GPR), as a Non Destructive Testing (NDT) technique, is an example of a non-intrusive technique that favors over the methods mentioned above for assessing compaction quality of asphalt pavements, since it allows measurement of all mat areas. Further, research studies in recent years have shown promising results with respect to its capability, coupled with the use of novel algorithms based on the dielectric properties of HMA, to predict the in-situ field density. In view of the above, field experimental surveys were conducted to assess the effectiveness of GPR methodology to estimate the in-situ compaction degree of several test sections. Moreover, considering also the field density results as obtained with traditional methods, comparative evaluation was conducted to assess the potential of using the GPR technique as a surrogate tool for pavement compaction quality purposes.

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An effective approach for road asset management through the FDTD simulation of the GPR signal

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Ground-penetrating radar is a non-destructive tool widely used in many fields of application including pavement engineering surveys. Over the last decade, the need for further breakthroughs capable to assist end-users and practitioners as decision-support systems in more effective road asset management is increasing. In more details and despite the high potential and the consolidated results obtained over years by this non-destructive tool, pavement distress manuals are still based on visual inspections, so that only the effects and not the causes of faults are generally taken into account. In this framework, the use of simulation can represent an effective solution for supporting engineers and decision-makers in understanding the deep responses of both revealed and unrevealed damages. In this study, the potential of using finite-difference time-domain simulation of the ground-penetrating radar signal is analyzed by simulating several types of flexible pavement at different center frequencies of investigation typically used for road surveys. For these purposes, the numerical simulator GprMax2D, implementing the finite-difference time-domain method, was used, proving to be a highly effective tool for detecting road faults. In more details, comparisons with simplified undisturbed modelled pavement sections were carried out showing promising agreements with theoretical expectations, and good chances for detecting the shape of damages are demonstrated. Therefore, electromagnetic modelling has proved to represent a valuable support system in diagnosing the causes of damages, even for early or unrevealed faults. Further perspectives of this research will be focused on the modelling of more complex scenarios capable to represent more accurately the real boundary conditions of road cross-sections.

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Evaluation of a highway pavement using non destructive tests: Falling Weight Deflectometer and Ground Penetrating Radar

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This paper presents the results of the application of Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR) to assess the bearing capacity of a rehabilitated flexible highway pavement that began to show the occurrence of cracks in the surface layer, about one year after the improvement works.

A visual inspection of the surface of the pavement was performed to identify and characterize the cracks. Several core drills were done to analyse the cracks propagation in depth, these cores were also used for GPR data calibration. From the visual inspection it was concluded that the development of the cracks were top-down and that the cracks were located predominantly in the wheel paths.

To determine the thickness of the bituminous and granular layers GPR tests were carried out using two horn antennas of 1,0 GHz and 1,8 GHz and a radar control unit SIR-20, both from GSSI.

FWD load tests were performed on the wheel paths and structural models were established, based on the deflections measured, through back calculation. The deformation modulus of the layers was calculated and the bearing capacity of the pavement was determined.

Summing up, within this study the GPR was used to continuously detect the layer thickness and the GPR survey data was calibrated with core drills. The results showed variations in the bituminous layer thickness in comparison to project data.

From the load tests it was concluded that the deformation modulus of the bituminous layers were also vary variable. Limitations on the pavement bearing capacity were detected in the areas with the lower deformation modulus.

This abstract is of interest for COST Action TU1208 Civil Engineering Applications of Ground Penetrating Radar.

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

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This work aims at presenting the ongoing activities and mid-term results of the COST (European COoperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar." Almost three hundreds 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, Egypt, Hong Kong, Jordan, Israel, Philippines, Russia, Rwanda, Ukraine, and United States of America. In September 2014, TU1208 has been praised 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. The Action is still open to the participation of new parties and it is possible to include, in the scientific work plan, new perspectives and activities. Scientists and scientific institutions willing to join are encouraged to contact the Chair of the Action and to follow the procedure described at http://www.cost.eu/participate/join_action. For more information on COST Action TU1208, please visit www.GPRadar.eu.

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GPR surveying of transport infrastructures and buildings; underground utility and void sensing - ongoing activities in Working Group 2 of COST Action TU1208

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This work aims at presenting the ongoing research activities carried out in Working Group 2 "GPR surveying of pavements, bridges, tunnels and buildings; underground utility and void sensing" of the COST (European COoperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" (www.GPRadar.eu).
The principal goal of the COST Action TU1208 is to exchange and increase scientific-technical knowledge and experience of Ground Penetrating Radar (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. Four Working Groups (WGs) carry out the research activities. WG1 focuses on the development of innovative GPR equipment dedicated for civil engineering applications. WG2 deals with the development of guidelines and protocols for the surveying, through the use of a GPR system, of transport infrastructure and buildings, as well as for the sensing of utilities and voids. WG3 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. WG4 is concerned with the use of GPR in fields different from the civil engineering, as well as with the integration of GPR with other non-destructive testing techniques. Each WG includes several Projects.
WG2 includes five Projects. Project 2.1 focuses on outlining "Innovative inspection procedures for effective GPR surveying of critical transport infrastructures (pavements, bridges and tunnels)." Project 2.2 is concerned with the development of "Innovative inspection procedures for effective GPR surveying of buildings." Project 2.3 deals with identifying "Innovative inspection procedures for effective GPR sensing and mapping of underground utilities and voids, with a focus to urban areas." Project 2.4 focuses on the development of "Innovative procedures for effective GPR inspection of construction materials and structures." The WG2 also includes Project 2.5 on the "Determination, by using GPR, of the volumetric water content in structures, sub-structures, foundations and soil," this is a topic of great interest in civil engineering, as water infiltration is often a relevant cause of degradation of structures, such as roads of bridges, and of rebar corrosion.
During the first year of the Action, information was collected and shared about state-of-the-art, ongoing studies, problems and future research needs, in the topics covered by the five above-mentioned Projects [1-3].
Based on the experience and knowledge gained from the in-depth review work carried out by WG2, several case studies were then conducted; they were presented during the Second General Meeting and the GPR 2014 conference [5, 6]. Furthermore, the extension of GPR application to railways track ballast assessment was demonstrated [7].
The WG2 identified reference test-sites, suitable to compare inspection procedures or to test GPR equipment. The IFSTTAR geophysical test site is an open-air laboratory including a large and deep area, filled with various materials arranged in horisontal compacted slices, separated by vertical interfaces and water-tighted in surface; several objects as pipes, polystyrene hollows, boulders and masonry are embedded in the field [4]. The IFSTTAR full-scale APT facility is an outdoor circular carousel dedicated to full-scale pavement experiments, consisting of a central tower and four long arms equipped with wheels, running on a circular test track [4].
Furthermore, the WG2 is building a database of available experimental results, which are at the disposal of WG3 Members to test their electromagnetic modeling/inversion/data-processing methods.
Another interesting and promising WG2 initiative that has to be mentioned is the development of a Catalogue of European test sites and laboratories for the testing of GPR equipment, methodology and procedures, that is being coordinated by France and Italy. The catalogue will represent a useful tool for the GPR community and it will contribute to identifying new cooperation possibilities among research groups, to clarifying which

are the missing testing facilities in the various European regions, and to addressing current or future research needs.

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Detection of Two Buried Cross Pipelines by Observation of the Scattered Electromagnetic Field

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In this work we present a numerical study on the effects that can be observed in the electromagnetic scattering of a plane wave due to the presence of two crossed pipelines buried in a half-space occupied by cement. The pipeline, supposed to be used for water conveyance, is modeled as a cylindrical shell made of metallic or poly-vinyl chloride (PVC) material. In order to make the model simpler, the pipelines are supposed running parallel to the air-cement interface on two different parallel planes; moreover, initially we suppose that the two tubes make an angle of 90 degrees. We consider a circularly-polarized plane wave impinging normally to the interface between air and the previously-mentioned medium, which excites the structure in order to determine the most useful configuration in terms of scattered-field sensitivity. To perform the study, a commercially available simulator which implements the Finite Element Method was adopted. A preliminary frequency sweep allows us to choose the most suitable operating frequency depending on the dimensions of the commercial pipeline cross-section. We monitor the three components of the scattered electric field along a line just above the interface between the two media. The electromagnetic properties of the materials employed in this study are taken from the literature and, since a frequency-domain technique is adopted, no further approximation is needed. Once the ideal problem has been studied, i.e. having considered orthogonal and tangential scenario, we further complicate the model by considering different crossing angles and distances between the tubes, in two cases of PVC and metallic material. The results obtained in these cases are compared with those of the initial problem with the goal of determining the scattered field dependence on the geometrical characteristics of the cross between two pipelines.
One of the practical applications in the field of Civil Engineering of this study may be the use of ground penetrating radar (GPR) techniques to monitor the fouling conditions of water pipelines without the need to intervene destructively on the structure.

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E^2GPR - *Edit your geometry, Execute GprMax2D and Plot the Results!*

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In order to predict correctly the Ground Penetrating Radar (GPR) response from a particular scenario, Maxwell's equations have to be solved, subject to the physical and geometrical properties of the considered problem and to its initial conditions. Several techniques have been developed in computational electromagnetics, for the solution of Maxwell's equations. These methods can be classified into two main categories: differential and integral equation solvers, which can be implemented in the time or spectral domain. All of the different methods present compromises between computational efficiency, stability, and the ability to model complex geometries. The Finite-Difference Time-Domain (FDTD) technique has several advantages over alternative approaches: it has inherent simplicity, efficiency and conditional stability; it is suitable to treat impulsive behavior of the electromagnetic field and can provide either ultra-wideband temporal waveforms or the sinusoidal steady-state response at any frequency within the excitation spectrum; it is accurate and highly versatile; and it has become a mature and well-researched technique. Moreover, the FDTD technique is suitable to be executed on parallel-processing CPU-based computers and to exploit the modern computer visualisation capabilities.
GprMax [1] is a very well-known and largely validated FDTD software tool, implemented by A. Giannopoulos and available for free public download on www.gprmax.com, together with examples and a detailled user guide. The tool includes two electromagnetic wave simulators, GprMax2D and GprMax3D, for the full-wave simulation of two-dimensional and three-dimensional GPR models. In GprMax, everything can be done with the aid of simple commands that are used to define the model parameters and results to be calculated. These commands need to be entered in a simple ASCII text file. GprMax output files can be stored in ASCII or binary format. The software is provided with MATLAB functions, which can be employed to import synthetic data created by GprMax using the binary-format option into MATLAB, in order to be processed and/or visualized. Further MATLAB procedures for the visualization of GprMax synthetic data have been developed within the COST Action TU1208 [2] and are available for free public download on www.GPRadar.eu. The current version of GprMax3D is compiled with OpenMP, supporting multi-platform shared memory multiprocessing which allows GprMax3D to take advantage of multiple cores/CPUs. GprMax2D, instead, exploits a single core when executed.
E^2GPR is a new software tool, available free of charge for both academic and commercial use, conceived to: 1) assist in the creation, modification and analysis of GprMax2D models, through a Computer-Aided Design (CAD) system; 2) allow parallel and/or distributed computing with GprMax2D, on a network of computers; 3) automatically plot A-scans and B-scans generated by GprMax2D. The CAD and plotter parts of the tool are implemented in Java and can run on any Java Virtual Machine (JVM) regardless of computer architecture. The part of the tool devoted to supporting parallel and/or distributed computing, instead, requires the set up of a Web-Service (on a server emulator or server); in fact, it is currently configured only for Windows Server and Internet Information Services (IIS). In this work, E^2GPR is presented and examples are provided which demonstrate its use. The tool can be currently obtained by contacting the authors. It will soon be possible to download it from www.GPRadar.eu.

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The influence of Stochastic perturbation of Geotechnical media On Electromagnetic tomography

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Electromagnetic tomography (CT) are commonly utilized in Civil engineering to detect the structure defects or geological anomalies. CT are generally recognized as a high precision geophysical method and the accuracy of CT are expected to be several centimeters and even to be several millimeters. Then, high frequency antenna with short wavelength are utilized commonly in Civil Engineering. As to the geotechnical media, stochastic perturbation of the EM parameters are inevitably exist in geological scales, in structure scales and in local scales, et al. In those cases, the geometric dimensionings of the target body, the EM wavelength and the accuracy expected might be of the same order. When the high frequency EM wave propagated in the stochastic geotechnical media, the GPR signal would be reflected not only from the target bodies but also from the stochastic perturbation of the background media. To detect the karst caves in dissolution fracture rock, one need to assess the influence of the stochastic distributed dissolution holes and fractures; to detect the void in a concrete structure, one should master the influence of the stochastic distributed stones, et al. In this paper, on the base of stochastic media discrete realizations, the authors try to evaluate quantificationally the influence of the stochastic perturbation of Geotechnical media by Radon/Iradon Transfer through full-combined Monte Carlo numerical simulation. It is found the stochastic noise is related with transfer angle, perturbing strength, angle interval, autocorrelation length, et al. And the quantitative formula of the accuracy of the electromagnetic tomography is also established, which could help on the precision estimation of GPR tomography in stochastic perturbation Geotechnical media.

Key words: Stochastic Geotechnical Media; Electromagnetic Tomography; Radon/Iradon Transfer.

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Electromagnetic modelling, inversion and data-processing techniques for GPR: ongoing activities in Working Group 3 of COST Action TU1208

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This work aims at presenting the ongoing research activities carried out in Working Group 3 (WG3) "EM methods for near-field scattering problems by buried structures; data processing techniques" of the COST (European COoperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" (www.GPRadar.eu).
The principal goal of the COST Action TU1208 is to exchange and increase scientific-technical knowledge and experience of GPR techniques in civil engineering, simultaneously promoting throughout Europe the effective use of this safe and non-destructive technique in the monitoring of infrastructures and structures.
WG3 is structured in four Projects. Project 3.1 deals with "Electromagnetic modelling for GPR applications." Project 3.2 is concerned with "Inversion and imaging techniques for GPR applications." The topic of Project 3.3 is the "Development of intrinsic models for describing near-field antenna effects, including antenna-medium coupling, for improved radar data processing using full-wave inversion." Project 3.4 focuses on "Advanced GPR data-processing algorithms."
Electromagnetic modeling tools that are being developed and improved include the Finite-Difference Time-Domain (FDTD) technique and the spectral domain Cylindrical-Wave Approach (CWA). One of the well-known freeware and versatile FDTD simulators is GprMax that enables an improved realistic representation of the soil/material hosting the sought structures and of the GPR antennas. Here, input/output tools are being developed to ease the definition of scenarios and the visualisation of numerical results. The CWA expresses the field scattered by subsurface two-dimensional targets with arbitrary cross-section as a sum of cylindrical waves. In this way, the interaction is taken into account of multiple scattered fields within the medium hosting the sought targets. Recently, the method has been extended to deal with through-the-wall scenarios.
One of the inversion techniques currently being improved is Full-Waveform Inversion (FWI) for on-ground, off-ground, and crosshole GPR configurations. In contrast to conventional inversion tools which are often based on approximations and use only part of the available data, FWI uses the complete measured data and detailed modeling tools to obtain an improved estimation of medium properties.
During the first year of the Action, information was collected and shared about state-of-the-art of the available modelling, imaging, inversion, and data-processing methods. Advancements achieved by WG3 Members were presented during the TU1208 Second General Meeting (April 30 – May 2, 2014, Vienna, Austria) and the 15th International Conference on Ground Penetrating Radar (June 30 – July 4, 2014, Brussels, Belgium).
Currently, a database of numerical and experimental GPR responses from natural and manmade structures is being designed. A geometrical and physical description of the scenarios, together with the available synthetic and experimental data, will be at the disposal of the scientific community. Researchers will thus have a further opportunity of testing and validating, against reliable data, their electromagnetic forward- and inverse-scattering techniques, imaging methods and data-processing algorithms. The motivation to start this database came out during TU1208 meetings and takes inspiration by successful past initiatives carried out in different areas, as the Ipswich and Fresnel databases in the field of free-space electromagnetic scattering, and the Marmousi database in seismic science.

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Determination, by using GPR, of the volumetric water content in structures, sub-structures, foundations and soil – ongoing activities in Working Project 2.5 of COST Action TU1208

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This work will endeavour to review the current status of research activities carried out in Working Project 2.5 "Determination, by using GPR, of the volumetric water content in structures, sub-structures, foundations and soil" within the framework of Working Group 2 "GPR surveying of pavements, bridges, tunnels and buildings; underground utility and void sensing" of the COST (European COoperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" (www.GPRadar.eu). Overall, the Project includes 55 Participants from over 21 countries representing 33 Institutions. By considering the type of Institution, a percentage of 64% (35 units) comes from the academic world, while Research Centres and Companies include, respectively, the 27% (15 units) and 9% (5 units) of Institutions. Geographically speaking, Europe is the continent most represented with 18 out of 21 countries, followed by Africa (2 countries) and Asia (1 country). In more details and according to the Europe sub-regions classification provided by the United Nations, Southern Europe includes 39% of countries, Western Europe 27%, while Northern and Eastern Europe are equally present with 17% of countries each.

Relying on the main purpose of Working Project 2.5, namely, the ground-penetrating radar-based evaluation of volumetric water content in structures, substructures , foundations, and soils, four main issues have been overall addressed over the first two years of activities. The first one, has been related to provide a comprehensive state of the art on the topic, due to the wide-ranging applications covered in the main disciplines of civil engineering, differently demanding. In this regard, two main publications reviewing the state of the art have been produced [1,2]. Secondly, discussions among Working Group Chairs and other Working Project Leaders have been undertaken and encouraged to avoid the risk of overlapping amongst similar topics from other Working Projects which directly could have dealt with moisture evaluation. As a result, independent and complementary targets have been singled out. To cite a few, interesting exchange of views took place in both the First and Second Action General Meetings of Rome and Vienna, respectively, in July 2013 and May 2014. In addition, a questionnaire with a relevant list of topics together with the identification of test scenarios for advanced comparison of inspection procedures have gathered invaluable information on the main expertises, fields of application, and equipments managed by the Project participants. The heterogeneous scenario outlined consequently, has indeed represented the third main issue to address. According to the Participants responses, roads were found to be the main target investigated (53%) so far, followed by soil materials (21%). In line with this, asphalt and compacted loose materials gathered the main interest among the main constituent materials with, respectively, 39% and 22%, as well as organic soils (22%). In this framework, the intermediate scale of investigation s, i.e., $0.01\ \mathrm{m}^2 < s < 100\ \mathrm{m}^2$, was found to be the most used for surveying. Finally, the fourth issue has been focused at avoiding the research to get blocked by ensuring a continuous updating of the latest results in moisture assessment using ground-penetrating radar achieved by Project 2.5 Participants [3-9].

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Medway Tunnel Road Pavement Survey Using Different Frequency GPR Antenna Systems – A Case Study

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This presentation reports on an extensive survey carried out on a section (just outside the westbound end of the tunnel portal) of the Medway Tunnel in North Kent, UK. The Medway Tunnel provides a dual carriageway road crossing under the River Medway between Chatham and Strood. It is 725 metres long from portal to portal and consists of three sections. The appearance of repeated cracking of the road surface in this particular section of the tunnel suggested either a steady movement of the ground or possible undermining due to an underground watercourse. Ironically, the design and construction of the road had been realised to prevent any form of structural movement. It was deemed necessary to perform a Ground Penetrating Radar (GPR) survey in order to confirm underground construction details of the road in this section of the tunnel.

This presentation reports on the detailed survey and the challenges encountered during the operation, which utilised four different frequency GPR systems including 2GHz, 900MHz, 600MHz and 200MHz antennas. The presentation will also describe how decisions were made to carry out supplementary surveys based on results obtained on-site (via primary data processing) and observations made during the survey.

A summary of results will be presented individually for each antenna system used, as well as comparisons between each antenna system. Results will then be mapped against the design drawings available for confirmation of construction configurations.

In conclusion, the presentation will demonstrate that the tunnel road pavement is not constructed as per the information provided (design drawings). Results will clearly indicate that there is no second reinforced concrete layer present in this particular section of the road pavement (contrary to what was originally believed) and will present the actual road construction in comparison with the design drawings.

The results will confirm that there is no underground watercourse present in this particular section of the tunnel (at 2-3 m depth). However, it will confirm the presence of an unknown feature at a depth of 1.2m below road surface.

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Integrated, Dual Orthogonal Antennas for Polarimetric Ground Penetrating Radar

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Ground penetrating radar systems are mostly equipped with single polarized antennas, for example with single linear polarization or with circular polarization. The radiated waves are partly reflected at the ground surface and very often the penetrating waves are distorted in their polarization. The distortion depends on the ground homogeneity and the orientation of the antennas relative to the ground structure. The received signals from the reflecting objects may most times only be classified according to their coverage and intensity. This makes the recognition of the objects difficult or impossible.
In airborne and spaceborne Remote Sensing the systems are meanwhile mostly equipped with front ends with dual orthogonal polarized antennas for a full polarimetric operation. The received signals, registered in 2x2 scattering matrices according to co- and cross polarization, are processed for the evaluation of all features of the targets. Ground penetrating radars could also profit from the scientific results of Remote Sensing. The classification of detected objects for their structure and orientation requires more information in the reflected signal than can be measured with a single polarization [1, 2].
In this paper dual linear, orthogonal polarized antennas with a common single, frequency independent phase center, are presented [3]. The relative bandwidth of these antennas can be 1:3, up to 1:4. The antenna is designed to work in the frequency range between 3 GHz and 11 GHz, but can be easily adapted to the GPR frequency range by scaling.
The size of the antenna scaled for operation in typical GPR frequencies would approximately be 20 by 20 cm^2. By the implementation in a dielectric carrier it could be reduced in size if required. The major problem for ultra wide band, dual polarized antennas is the frequency independent feed network, realizing the required phase shifts. For these antennas a network, which is frequency independent over a wide range, has been developed [4].
If OFDM signals are used for the radiation, the carriers can be split in even and odd carriers and fed to the two orthogonally polarized transmit antennas. By using OFDM, the de-correlation of the two subcarrier groups becomes inherently high. Due to the orthogonality of OFDM subcarriers the de-correlation only depends on the quality of the hardware and the signal processing. They can be simultaneously radiated and received by the two antennas. This could result in a significant improvement of the GPR sensor system.
The antenna has been realized and first measurements have been conducted.
During the forthcoming EGU 2015 General Assembly the detailed electromagnetic background and the function of the dual linear, orthogonal polarized antenna will be presented as well as results in GPR relevant frequencies. Also, an approach of a planar feeding network will be presented.

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

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Design and testing of Ground Penetrating Radar equipment dedicated for civil engineering applications: ongoing activities in Working Group 1 of COST Action TU1208

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This work aims at presenting the ongoing research activities carried out in Working Group 1 “Novel GPR instrumentation” of the COST (European COoperation in Science and Technology) Action TU1208 “Civil Engineering Applications of Ground Penetrating Radar” (www.GPRadar.eu).

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

Working Group 1 (WG1) of the Action focuses on the development of innovative GPR equipment dedicated for civil engineering applications. It includes three Projects. Project 1.1 is focused on the “Design, realisation and optimisation of innovative GPR equipment for the monitoring of critical transport infrastructures and buildings, and for the sensing of underground utilities and voids.” Project 1.2 is concerned with the “Development and definition of advanced testing, calibration and stability procedures and protocols, for GPR equipment.” Project 1.3 deals with the “Design, modelling and optimisation of GPR antennas.”

During the first year of the Action, WG1 Members coordinated between themselves to address the state of the art and open problems in the scientific fields identified by the above-mentioned Projects [1, 2]. In carrying our this work, the WG1 strongly benefited from the participation of IDS Ingegneria dei Sistemi, one of the biggest GPR manufacturers, as well as from the contribution of external experts as David J. Daniels and Erica Utsi, sharing with the Action Members their wide experience on GPR technology and methodology (First General Meeting, July 2013). The synergy with WG2 and WG4 of the Action was useful for a deep understanding of the problems, merits and limits of available GPR equipment, as well as to discuss how to quantify the reliability of GPR results.

An innovative reconfigurable ground-coupled stepped-frequency GPR is being studied and optimised by a group of WG1 Members; it was designed in Italy and is equipped with two bow-tie antennas, with a series of switches along their arms, so that their size can be varied. The system was tested in several sites, both indoor and outdoor, in comparison with a commercial ground-coupled pulsed system [1, 3, 4]. Subsequently, within a COST Short-Term Scientific Mission (STSM), the prototype device was sent to Norway and compared with a commercial ground-coupled stepped-frequency radar [5]. These experimental activities were fundamental to gain a deepen knowledge of the reconfigurable GPR prototype and to plan its improvement.

Another innovative system being designed within the Action and proposed by Italian Members, will allow investigating the mechanical properties of pavement, in addition to its geometrical and electromagnetic properties.

Cooperation with the COST Action IC1102 “Versatile, Integrated, and Signal-aware Technologies for Antennas (VISTA)” has been established, concerning the design of GPR antennas.

At least two more WG1 activities need to be mentioned, as they are very interesting and promising. The first one, coordinated by Italy and involving Members and external experts from Germany, United Kingdom, Japan and United States, is the development of a protocol providing recommendations for the safety of people and instruments in near surface geophysical prospecting, with a particular focus to the use of GPR.

The second initiative is called GPR4Everyone, it was proposed by Italy and consists in creating a virtual store of GPR equipment at the disposal of Members from inclusiveness Countries: some Institutes have GPR systems and complementary NDT equipment no longer used, while there are Institutes who cannot afford to buy a GPR; thus, the idea is to cense the unused equipment and make it available to be given for free to researchers from less research-intensive countries, as a small step to counterbalance research communities' unequal access to funding and resources distribution.

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Inertial and GPS data integration for positioning and tracking of GPR

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Nowadays many applications and studies use a Global Positioning System (GPS) to integrate Ground-Penetrating Radar (GPR) data [1-2]. The aim is the production of detailed detection maps that are geo-referenced and superimposable on geographic maps themes. GPS provides data to determine static positioning, and to track the mobile detection system path on the land. A low-cost standard GPS, like GPS-622R by RF Solutions Ltd, allows accuracy around 2.5 m CEP (Circular Error Probability), and a maximum update rate of 10 Hz. These accuracy and update rate are satisfying values when we evaluate positioning datum, but they are unsuitable for precision tracking of a speedy-mobile GPR system. In order to determine the relative displacements with respect to an initial position on the territory, an Inertial Measurement Unit (IMU) can be used. Some inertial-system applications for GPR tracking have been presented in recent studies [3-4]. The integration of both GPS and IMU systems is the aim of our work, in order to increase GPR applicability, e.g. the case of a GPR mounted on an unmanned aerial vehicle for the detection of people buried under avalanches [5]. In this work, we will present the design, realization and experimental characterization of our electronic board that includes GPS-622R and AltIMU-10 v3 by Pololu. The latter comprises an inertial-measurement unit and an altimeter. In particular, the IMU adopts L3GD20 gyro and LSM303D accelerometer and magnetometer; the digital barometer LPS331AP provides data for altitude evaluation. The prototype of our system for GPR positioning and tracking is based on an Arduino microcontroller board.

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Exchanging knowledge and working together in COST Action TU1208: Short-Term Scientific Missions on Ground Penetrating Radar

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This work aims at presenting the scientific results stemming from six Short-Term Scientific Missions (STSMs) funded by the COST (European COoperation in Science and Technology) Action TU1208 “Civil Engineering Applications of Ground Penetrating Radar” (Action Chair: Lara Pajewski, STSM Manager: Marian Marciniak). STSMs are important means to develop linkages and scientific collaborations between participating institutions involved in a COST Action. Scientists have the possibility to go to an institution abroad, in order to undertake joint research and share techniques/equipment/infrastructures that may not be available in their own institution. STSMs are particularly intended for Early Stage Researchers (ESRs), i.e., young scientists who obtained their PhD since no more than 8 years when they started to be involved in the Action. Duration of a standard STSM can be from 5 to 90 days and the research activities carried out during this short stay shall specifically contribute to the achievement of the scientific objectives of the supporting COST Action.

The first STSM was carried out by Lara Pajewski, visiting Antonis Giannopoulos at The University of Edinburgh (United Kingdom). The research activities focused on the electromagnetic modelling of Ground Penetrating Radar (GPR) responses to complex targets. A set of test scenarios was defined, to be used by research groups participating to Working Group 3 of COST Action TU1208, to test and compare different electromagnetic forward- and inverse-scattering methods; these scenarios were modelled by using the well-known finite-difference time-domain simulator GprMax. New Matlab procedures for the processing and visualization of GprMax output data were developed.

During the second STSM, Iraklis Giannakis visited Lara Pajewski at Roma Tre University (Italy). The study was concerned with the numerical modelling of horn antennas for GPR. An air-coupled horn antenna was implemented in GprMax and tested in a realistically modelled pavement scenario; moreover, the horn was compared with a previously-implemented ground-coupled bowtie antenna. The numerical results indicate that air-coupled antennas receive clear reflections from distinct layers within the pavement but they are incapable in the considered setting to detect cracks filled with air. On the other hand, by using ground-coupled antennas it is easier to interpret hyperbolic responses from the buried cracks. The developed modelling framework is a powerful tool in evaluating the performance of high-frequency GPR transducers in realistic situations and this approach can lead to better design of GPR antennas.

The third STSM was carried out by Sonia Santos Assunçao visiting Klisthenis Dimitriadis at Geoservice (Greece). They worked at the non-destructive inspection of the Tholos Tomb of Acharnon. The unknown thickness of the Tomb walls was determined by using a GPR. Data were plotted in impressive circular radargrams. Discontinuities in the measured data were identified and associated to fissures or voids, indicating internal and superficial damages of the Tomb. A combination of GPR with electrical resistivity tomography allowed a more accurate data interpretation. Vibrations in the Tomb were quantified by using seismic measurements and endoscopy was used to confirm the thickness of the walls.

During the fourth STSM, Philippe De Smedt visited Immo Trinks at the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology. The research activities regarded the reconstruction of prehistoric environments at Stonehenge, by means of multiple electromagnetic survey methods. Different datasets

were processed, analysed and compared: data from a multi-receiver electromagnetic induction survey (collected by the ORBit research group from Ghent University, Belgium), and data from a 3D GPR survey (collected by the Ludwig Boltzmann Institute for Virtual Archaeology and Archaeological Prospection, Austria). The aim was that of creating a robust methodological foundation for the combined analysis of electromagnetic-induction and GPR data.

The fifth STSM was carried out by Loredana Matera, who visited Jacopo Sala at 3d-radar (Norway). They tested an innovative reconfigurable stepped-frequency GPR, designed and realised in Italy. The prototype was compared with commercial equipment produced in Norway. Through laboratory experiments as well as outdoor campaigns in urban scenarios with archaeological remarks, a deeper knowledge of the Italian prototype was achieved and plans were made to improve it.

Finally, Nicolas Pinel visited Sébastien Lambot at the Université catholique de Louvain (UCL); the last STSM presented in this abstract, was devoted to investigating how to model the effect of soil roughness in the inversion of ultra wide-band off-ground monostatic GPR signals. The aim of this research is the noninvasive quantification of soil properties through the use of GPR. The work focused on incorporating the improved asymptotic forward electromagnetic model developed by Pinel et al. in the multilayer Green function code developed at UCL.

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Minimising street work disruption by mapping cavities derived from 3D GPR-data: a new sewerage project in Torrente (Valencia, Spain)

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Ground penetrating radar is usually employed for non-destructive detection of cavities in karst areas and road maintenance. This paper describes the inspection for cavity detection in a street located in Torrente (Valencia, Spain) where a new sewerage project was planned.

Torrente population growth (more than 80,000 inhabitants last year) has caused urban development southwards from its downtown. According to municipality geologic configuration, new urbanized areas are located in mountains composed of limestone with presence of karst systems. During excavation work for a sewerage system installation, a 4 x 2 x 1.5 m shallow cave was found in one planned street. For this reason, digging activities were stopped and a GPR survey was carried out on the street. A 1x1 m grid was collected using a GSSI SIR-3000 equipment. A 400 MHz frequency antenna was used for reaching 2.5 m approx. depth, attending the characteristics of the discovered cave and the excavation project depth. GPR records were calibrated in situ, thanks to the unearthed cavity.

The 3D GPR-data interpretation mapped several caves only on one side of the street. The detected cavities coincided with the sewerage system layout. These underground spaces were isolated from each other, as small individual karst caves. The outcomes of this study allowed the modification of the sewerage project. Therefore, the sewerage system layout was moved to the other side of the street where no cavities were detected with the GPR survey.

GPR is proved to be an efficient tool to be taken into consideration by civil engineers and architects for designing new infrastructures (e.g. sewerage systems) in urban planning areas. We conclude GPR helps minimising cost, time and inconveniences to neighbourhood during excavation works, especially in cities.

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Use of Ground Penetrating Radar at the FAA's National Airport Pavement Test Facility

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The Federal Aviation Administration (FAA) in the United States has used a ground-coupled Ground Penetrating Radar (GPR) at the National Airport Pavement Test Facility (NAPTF) since 2005. One of the primary objectives of the testing at the facility is to provide full-scale pavement response and failure information for use in airplane landing gear design and configuration studies. During the traffic testing at the facility, a GSSI GPR system was used to develop new procedures for monitoring Hot Mix Asphalt (HMA) pavement density changes that is directly related to pavement failure.

After reviewing current setups for data acquisition software and procedures for identifying different pavement layers, dielectric constant and pavement thickness were selected as dominant parameters controlling HMA properties provided by GPR. A new methodology showing HMA density changes in terms of dielectric constant variations, called dielectric sweep test, was developed and applied in full-scale pavement test. The dielectric constant changes were successfully monitored with increasing airplane traffic numbers. The changes were compared to pavement performance data (permanent deformation). The measured dielectric constants based on the known HMA thicknesses were also compared with computed dielectric constants using an equation from ASTM D4748-98 Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar. Six inches diameter cylindrical cores were taken after construction and traffic testing for the HMA layer bulk specific gravity. The measured bulk specific gravity was also compared to monitor HMA density changes caused by aircraft traffic conditions.

Additionally this presentation will review the applications of the FAA's ground-coupled GPR on embedded rebar identification in concrete pavement, sewer pipes in soil, and gage identifications in 3D plots.