The European GIGA Project

Guido Manacorda
Georadar Division
IDS Ingegneria dei Sistemi SpA
Pisa, Italy
g.manacorda@ids-spa.it

Howard Scott
Managing Director
OSYS Technology Limited
Newcastle upon Tyne, United Kingdom
howard.scott@osys.co.uk

Paul D Loach
Underwater Signatures
IDS (UK) Ltd
Southampton, United Kingdom
p.loach@ids-spa.it

John J Kazik
Above Water EM Modelling
IDS (UK) Ltd
Southampton, United Kingdom
j.kazik@ids-spa.it

Dave Pinchbeck
General Secretary
GERG – The European Gas Research Group
Brussels, Belgium
gerg@arcadis.be

Meinolf Remeil
Coordination Department
Tracto-Technik Spezialmaschinen (TT Group)
Lennestadt, Germany
marketing@tracto-technik.de

Jean-Pierre Capdevielle, Pascal-Fabien Fournier
Direction de la Recherche
Gaz de France
Paris, France
Pascal-fabien.fournier@gazdefrance.com

***Abstract*—The demand for natural gas is growing steadily satisfying it requires the development of safe, well-controlled and reliable gas network at minimal cost. Further, the worldwide demand for telecommunication links is increasing at a remarkable pace and this has generated a need for new installations, especially for connections to ISDN services, cable TV, etc. Digging, however, without reliable information on existing utilities and the local geology, can be problematic, even dangerous. Instances of damage to buried plant would be reduced by the use of reliable location techniques.**

The GIGA project is a European Commission funded collaborative research study, which aims to inform and enable the design and build of a new and reliable Ground Penetrating Radar. The project involves end-users and GPR suppliers and combines bottom-up and top-down approaches to innovative GPR research.

Keywords-GPR; Utilities locating techniques; Simulation

I. INTRODUCTION

The steadily increasing demand for natural gas necessitates the development of safe, well-controlled and reliable gas networks, at minimal cost. A similar situation exists in the telecommunications industry where there is a voracious demand for increased capacity and new installations. For utilities wishing to install new infrastructure, this presents problems associated with the detection and location of buried objects, particularly small non-metallic pipelines and cables, in difficult soil conditions.

In this area, Ground Penetrating Radar has proved to be very attractive, mainly because it is the only technique, amongst the various state-of-the-art methods available, that is capable of accurately locating metallic and non-metallic buried objects without prior knowledge of their position. However, poor results due to the limited performance achieved by unsuitable equipment and/or unskilled radar operators has, so far, made drilling contractors unwilling to rely totally upon GPR.

Surprisingly, current developments in GPR are oriented towards visualisation improvement, using 3-dimensional plots and GPS data, with little or no attention being paid to addressing the basic, but challenging, radar signal detection problem. Clearly, visualisation developments will not increase system performance but will merely improve the aesthetics of the display. Enhanced graphics software will not solve the basic signal problem or improve the detection performance when the received signal is too weak, as would be the case in wet, muddy ground, or when obscured by high levels of clutter.

As a consequence, the GIGA project was established with the main objective of enabling the design of a novel Ground Penetrating Radar capable of providing enhanced performance, especially in terms of location accuracy and detection robustness.

II. THE GIGA PROJECT

The GIGA (**G**round Penetrating Radar **I**nnovative research for highly reliable robustness/accuracy **G**as pipe detection/location) project is a European Commission funded collaborative research study to inform and enable the design and build of a new and reliable Ground Penetrating Radar (GPR). Its overall objective is the design of a GPR with a detection performance that is significantly improved compared to the present generation of equipment, and robust enough to be used with confidence on diverse types of pipes buried in a wide range of soil types.

The project's work-plan shown in Figure 1, has comprised four main activities:

- a meticulous assessment of the performance of a state-of-the-art GPR in surveys conducted under controlled conditions at dedicated test sites;
- analysis of possible radar technology improvements, including multi-parameter/variable configurations of the radar;
- development of new simulation tools to enable a fresh, theoretical view of the problem to form the basis of an improved equipment design;
- development of software processing tools to reduce the need for highly trained operators.

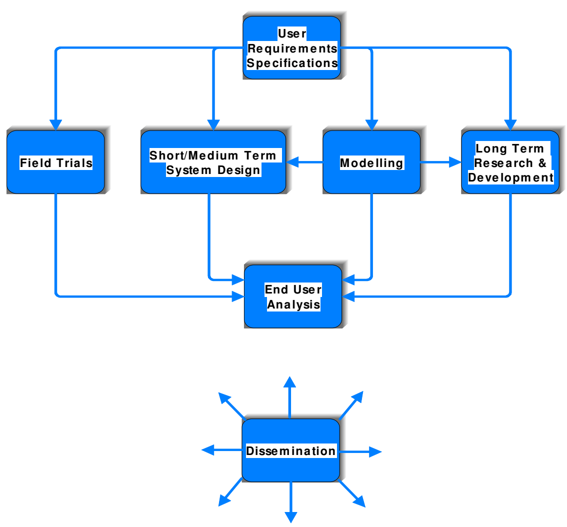

Figure 1. GIGA's work-plan

The first stage of the research activities was the collection and evaluation of the requirements specification as listed by European utilities (gas, water, telecom, electricity, etc.) and European directional drilling companies.

Based on the measurement of performance achievable with current technology, it was possible to specify the design of a novel GPR system that is best able to meet, in the short-term, most of the end-user requirements (bottom-up approach). Simultaneously, the "top-down" research allowed the definition of the issues that have to be addressed in further research phases, to provide further performance improvements in terms of penetration depth and the range of soil types and conditions in which GPR can operate.

The following paragraphs describe the main results achieved during the project.

A. Field Trials

Ideally, a pipe location system should have the capability to detect and map all classes of buried pipes and cables. For the system to be accepted by users as reliable, its ability to detect real buried objects must be accompanied by a low rate of false target generation, and a low rate of failure to detect real buried objects.

To assess the performance achievable by a GPR when used for detecting utilities, an intensive survey was carried out in the trial area established by Gaz de France in Saint Denis (Paris – France). On this test site, materials covering the pipe were chosen to be as representative as possible of real world conditions, and the pipes and cables together with their configuration and burial depths are designed both to be representative and to test the major aspects of Ground Penetrating Radar performance.

Figure 2. Field trial in Saint Denis (Paris – France)

By analysing the huge amount of data collected during the trial, and taking account of results obtained from other trials to test the validity of the results of GdF trials, it was possible to verify that IDS' state-of-the-art equipment achieved a detection rate better than 80% to 2 metres depth, a false alarm rate less than 10%, a 40 mm accuracy of location both in the horizontal and vertical plane and a resolution better than 300 mm.

These results confirm that the GPR can be a more than useful pipe location tool. The analysis, however, has also shown that two important issues need to be addressed, in both the short and long term; these are penetration depth and the detection of small diameter plastic pipes (and, perhaps, other small, non-metallic targets) particularly where the ground consists of highly conductive material.

B. Modelling

During the GIGA project simulation tools capable of modelling the electrical behaviour of buried targets and their environment were developed.

In particular, two different tools were utilised during the project. The first uses the Transmission Line Matrix (TLM) method for reproducing typical GPR scenarios by working in time-domain; the second uses an approximation based upon optical propagation laws and ray tracing rather than solving Maxwell's equations. This latter method is very economical in processing time, it cannot, however, be used for analysing complex scenarios. Only the TLM method will be described here.

The TLM method

The transmission line matrix method is a relatively new development in computational electromagnetism (see [1], [2] and [3]). It is a powerful, general-purpose tool for modelling a wide range of electromagnetic problems. The TLM technique can model lossy dielectric materials and those with finite conductivity. Features such as thin wires and layers of thin material layers can also be modelled.

For that reason, the technique was tested for modelling GPR scenarios, including complex geometries and frequency dependent material properties, as well as GPR antennas.

The modelling of structures is performed by discretising the problem space into a number of cells on a Cartesian grid. These cells may vary in size to provide graded volumetric meshing for arbitrary shapes and structures. In this way, the problems with modelling areas of fine detail are largely eliminated (though it still is a staircase approximation to the geometry).

During the project, the method was assessed by simulating a scenario representing an actual test site consisting of 5 pipes, metallic and non-metallic, buried in a pit filled with sand. The relative electrical permittivity and the electrical conductivity of the sand were measured through borehole measurements made over the range of frequencies used by the GPR.

The first part of the modelling process is to develop a CAD representation of the scenario, then convert that into a mesh. For TLM, a Cartesian mesh is required with one set of electromagnetic material properties in each cell. The TLM mesh for the GPR scenario is shown in Figure 3. In addition to meshing the CAD representation, the air above the pit was also meshed to a height of 20 cm.

The dimensions of each cell are determined by the electromagnetic wavelength within the cell at the highest frequency of interest. The edge length of a cell is not allowed to exceed one-tenth of the wavelength. Therefore, in order to model the different material properties correctly, a variable cell size is required.

The transmitting and receiving antennas are modelled using single wires loaded at one end, placed 9 cm apart and 1.5 cm above the ground[1].

A radargram for this scenario was generated using TLM by modelling the GPR equipment at 300 locations along the ground. Hence, the output from the solver is 300 waveforms of the current in the receiver. In order to simulate the GPR correctly, these waveforms were convolved with the measured waveform of the 600 MHz IDS GPR antenna.

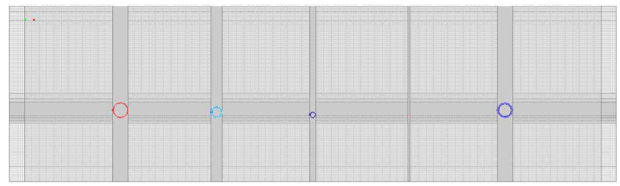

Figure 3. TLM mesh of the GPR scenario.

A comparison between the measured and predicted radargrams for this scenario is shown in Figure 4. It can be noted that there is good agreement between the shape and strength of the radar returns from the pipes.

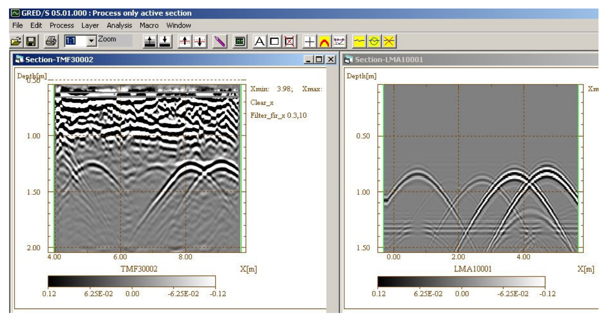

Figure 4. Comparison between measured and predicted radargrams.

Thus, by using these tools and by varying the characteristics of the dielectric medium as well as the physical properties and geometric arrangement of targets, it is possible to provide useful information on the fundamental limits of GPR detection and to guide equipment design decisions.

C. Short/Medium Term Hardware Developments

This phase of GIGA was aimed at the design of a new GPR system to be implemented in the short term that would be capable of fulfilling most of the end-user requirements. However, because low cost technology suitable for implementing FMCW radars[2] is not currently available, the GIGA short term GPR will be an impulsive system with its own restrictions in terms of dynamic range and, consequently, in penetration depth.

Its architecture uses an array of multi-frequency antennas, lined up in the transversal direction, with respect to the

[1] These dimensions are true for an IDS TR 600 MHz antenna.
[2] These systems are claimed to be capable of guaranteeing a wider dynamic range and a bigger penetration depth.

direction of movement of the radar, and operating simultaneously. The use of an array of antennas has previously been proved to increase the reliability of detection simply because pipes produce echoes (hyperbolas) in the same positions in most (ideally in all) of the collected radargrams; therefore, the operator can easily distinguish this class of target from a concentrated one (e.g. a stone) and, hence, performance in terms of probability of detection, is increased.

The choice of the antennas comprising the array, is dictated by the requirements in terms of penetration depth, resolution (both vertical and horizontal) and the detection of small, plastic pipes that form an important class of objects that users wish to locate.

Unfortunately, some of these requirements are mutually in conflict as high frequencies are needed to provide resolution but they cannot provide the desired penetration depth. For that reason, the approach that has been adopted for an impulsive system for the GIGA short-term equipment is the contemporaneous use of wide-band multi-frequency antennas. Therefore the short-term solution will utilize different antenna modules, integrated into a single unit, to cover the frequency range 150MHz to 2GHz, in order to be able to satisfy those requirements.

D. Short/Medium Term Data Analysis Developments

In addition to the hardware issues addressed during the GIGA project, consideration was also given to data analysis techniques that reduce the dependence on highly trained operators for the quality of information obtained using the GPR technique.

Data reduction techniques have been developed to highlight the strictly useful information and to make the analysis as quick and easy as possible for the operator.

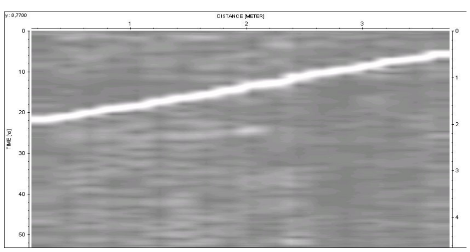

Figure 5. GPR imaging of a buried sloping pipe

A key achievement of the data analysis development is a precise evaluation of the GPR waveform propagation velocity. This increases the accuracy of the estimate of the depth of utilities detected by the system (see [4]).

III. Long Term research

In the longer term, the main objective of GPR design is to achieve a clutter free dynamic range that is as large as possible, mainly to increase the depth of penetration.

A secondary objective is to control the frequency range so that it closely matches the requirements of target detection and antenna characteristics.

In GIGA, the use of stepped frequency sources, and receivers based upon homodyne detection and balanced mixers, has been studied. In theory, such systems possess superior dynamic range and stability compared to pulse systems, and allow control of the frequency range. At present, the main drawback to this approach is the high cost of the microwave sources. It is possible, however, that the particular requirements of GPR may allow a relaxation of the specification of a stepped frequency microwave sources that could offer significant cost reductions.

Thus, in a longer term, it seems to be reasonable to assert that a Stepped Frequency Continuous Wave GPR will constitute a further step towards addressing and possibly overcoming the remaining limitations of the technique.

IV. Conclusions

GIGA is a research study, which was established to inform and enable the design and build of a new, dependable Ground Probing Radar (GPR). Its eventual objective is a GPR specifically designed to provide the precision and high resolution required for no-dig installation of gas pipelines by means of Horizontal Directional Drilling (HDD).

A detailed knowledge of the sub-surface layout is essential before excavation or directional drilling is employed, if one is to reduce the probability of damage to buried plant and the potential for injury to personnel.

The availability of an improved GPR will lead to a reduction in the cost of installing gas pipelines and telecommunications networks, as well as a further investment cost saving that will arise from the increased use of trenchless directional drilling enabled by GPR.

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References

[1] C Christopoulos, The Transmission Line Modelling method, IEEE/Oxford University Press, IEEE ISBN 0-7803-1017-9, OUP ISBN 0-19-856533-X, 1995

[2] Kazik, J J, Prediction of shielding performance via the Transmission Line Matrix Method (TLM), Colloquium on Shielding and Grounding Digest, IEE, London, 2000

[3] Kazik, J J, Validation of time domain Transmission Line Matrix Method (TLM) for composite materials, Fourth International Workshop on Computational Electromagnetics in Time Domain: TLM/FDTD and Related Techniques, University of Nottingham, UK, 17-19 September 2001, published by University of Nottingham, ISBN 0-9541146-0-4, 2001

[4] P. Falorni, L. Capineri, L. Masotti and G. Pinelli, 3-D Radar imaging of buried utilities by features estimation of hyperbolic diffraction patterns in Radar scans, published in the proceedings of this conference.