WATERPIPE Newsletter

Editorial

Many EU cities are experiencing increasing problems with their water pipeline infrastructure. The cost of replacing these old, worn-out systems, if left to deteriorate beyond repair, is astronomical and clearly beyond the resources of many communities. Replacement, however, is not the only choice, as many of these systems can be rehabilitated at 30 to 70 percent of the cost of replacement. Accordingly, resources allocated to address pipeline rehabilitation management issues are increasing. Due to the emphasis on sustainable management, risk-based approaches for the rehabilitation management of the water supply network need to be developed, as well as technologies for the inspection and evaluation of the pipeline conditions. This is the aim of WATERPIPE project.

WATERPIPE project contributes to the topic II.3.3 "Advanced Technologies for Locating, Maintaining and Rehabilitating Buried Infrastructures" of the "Global Change and Ecosystems" thematic sub-priority of the FP6, by developing new, reliable technologies for water distribution -incorporating also performance and risk based approaches- for locating assets, identifying defects and leaks, monitoring and rehabilitating the buried infrastructures. The main aim is to improve operation, rehabilitation, serviceability, pollution prevention and safety and thus minimising direct and indirect costs, including the environmental and socio-economic ones.

This Newsletter 2 aims to outline the Ground Penetrating Imaging Radar (GPIR) prototype architecture and specifications, both from the structural and software point of view. A brief overview of the preliminary measurements carried out in the first project phase are presented as well. As in the Newsletter 1, a section is also dedicated to dissemination activities carried out at EU level in order to make the project and the developed technologies known.

WATERPIPE Newsletters are sent to all the members of the WATERPIPE Mailing List, composed of stakeholders and operators of the water sector who have to deal with water pipeline infrastructure and decision making processes. Anyone interested in the WATERPIPE topic is invited to register to the WATERPIPE Mailing List (see Contacts section).

WATERPIPE 2nd Newsletter

December 2008

Inside this issue:

Integrated High Resolution Imaging Ground Penetrating Radar and Decision Support System for WATER PIPEline Rehabilitation

European Commission co-funded project
6th Framework Program
Project no. 036887
Global Change and Ecosystems

www.waterpipe-eu.org

Introduction to the GPIR

The necessity of Ground Penetrating and Imaging Radars (GPIR) to obtain information of underground media has driven the design and development of several prototype experimental systems as early as 1970's. The initial systems operation principle was based on the use of short pulse transmissions toward the earth and measurement of echo signals using sampling methods.

In this type systems only a 1D in depth information is obtained and the measured echo signals, being an average of the antenna average the horizontal spatial resolution, cannot be better than 30-50 cm whilst penetration depth up to 1-2 m could be achieved depending on the losses of the ground medium. Horizontal mechanical scanning systems were also developed to provide the capability of automatic scanning of the surface. The possibility of using Frequency Modulation (FM) techniques was also investigated in few cases.

Only recently, because of the availability of high speed data acquisition, has there the possibility to develop wavefront measurement GPIR systems exists. The present approach is to design a time domain measurement ground penetrating system based on a mixed mode horizontal mechanical – electronic system receiver antenna system. This mixed approach keeps the complexity of the system to reasonable level.

In designing the WATERPIPE prototype system, a priori technology selections were carried out. The fundamental choices are:

- Use of Ultra Wideband (UWB) – short pulse transmission to light the earth medium.
- Measure the reflected waves on a surface of sufficient horizontal area to achieve a good spatial resolution in 3-D.
- Utilize mechanical and electronic scanning to measure and acquire the reflected- scattering signals.
- The processing of measured signals to be done on site and the presentation of images to be achieved in three dimensions in "real time".
- In order to explore wider areas, the system moves along a linear or curved path. Then, the Fundamental Operational Specifications (FOS) of the system was defined. The definition of the FOS is of paramount importance since their selection should comply with two requirements:
  - ⇒ Achieve the required imaging and operational characteristics of the GPIR on detecting water pipe faults and their nature.
  - ⇒ Not violate existing technology capabilities and, of course, physical limitations imposed by electromagnetic (E/M) theory.

Taking into account the above two conditions and the nature of the water pipe faults, the following FOS have been selected:

1. Maximum Imaging Depth: 2 meters from the earth surface.
2. Spatial-imaging resolution in three dimensions: better than 5 cm.
3. Acquisition time of underground image of 1X1 m^2 in less than 10 seconds.
4. The radar capable to be mounted on a cart to carry continuous measurements along a path.
5. Power consumption requirements: less than 500 Watt.
6. The operation of the GPIR system must be fully automatic without any intervention of the operator (only requiring supervision in case something goes wrong because of the prototype nature of the system).
7. The GPIR should be capable of surveying 1km in a time of less than 2.8 hours.

Operation Principle

The operation of the High Resolution GPIR is based on the following principles:

- A short duration (nanosecond) pulsed signal is periodically generated by the short pulse transmitter. The Pulse Repetition Frequency (PRF) is several MHz. The high PRF is useful to achieve the generation of 3-D underground environment images in minimum time. The output pulse is driven to a wide band transmitting antenna emitting the pulsed radiation towards the earth. The energy content of the pulse is peaked in the spectral region 500-1500 MHz depending on the selected pulse duration.
- The radiation of the pulsed signals results in the illumination of the ground environment with the penetration of the wide band signals. The electromagnetic (E/M) properties of the earth medium results in strong dispersion phenomena as the earth is an inhomogeneous medium and because of the existence of artificial materials such as water pipes, the subject of our interest. Therefore, the response from the underground medium is highly complicated in terms of E/M properties.
- The reflected-scattered fields forming the underground environment is measured and recorded on a surface of 1×1 m^2 parallel to the earth medium. The measurement of field on this aperture is carried out with a density of 0.1×0.1 cm^2.
- The selection of the receiver antenna parameters are determined by the requirement of achieving underground 3-D imaging resolutions of 5 cm in all dimensions.
- The use of hybrid scanning technique results at any given instant in a single output, thus requiring only a single receiver channel which provides an effective multiplexing.
- The received signal is then filtered and amplified through a linear channel. This analog signal conditioning prepares the signal to drive the High Speed Analog to Digital Converter (A/D-C) operating at 1.5 G-Sample/second rate.
- The sampling is carried out with an 8-bits resolution and the measurement voltage value is stored in a buffer memory. In each measurement point averaging of recorded signals is carried out to improve the signal to noise ratio of the received signals. The number of averaged pulses will be of the order of 8-16 or even to 64 if this is required.
- The use of high PRF allows the averaging of a large number of pulses.
- The A/D-C circuit is triggered by the same master clock triggering the short pulse transmitter.

Why Ultra-Wideband (UWB) technology?

The use of UWB signals provides extensive information for the imaging of the underground target medium. At the end of each receiver scanning antenna, up to 400 reflected-scattered signal waveforms are available to the processing unit.

The reflected scattered waveforms is produced by acquiring, averaging and storing the real and imaginary parts of signals peaked by the 10 probe antennas placed along a linear line which in turn also scans the aperture along a vertical line.

Two alternative versions of the reconstruction algorithm are tested to observe the performance and select the most accurate one.

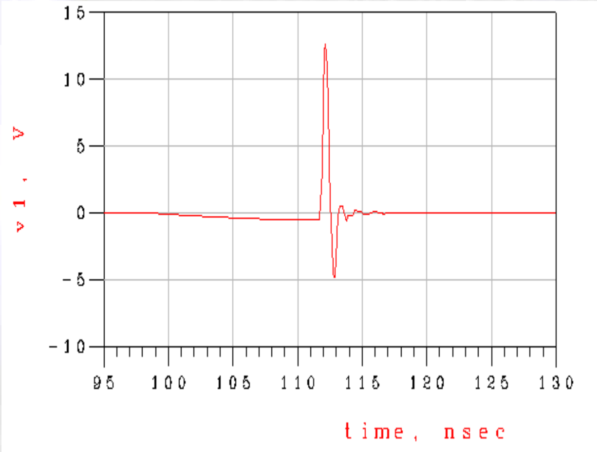

***Figure 1**. Transmitted Pulse*

GPIR system and Subunits Specifications

In terms of its main subunits, the designed and developed GPIR consists of the following:

1. Transmitter Unit (including Antenna)

A UWB signal generator is utilized to produce sub-nanosecond pulse (500-3000 ps). The peak pulse amplitude is of approx 20 Vp-p. This pulsed signal is conveyed to the transmitting antenna which is a Transverse E/M Flared Horn antenna. The ***transmitting antenna*** is fixed ***contrary to the receiving antenna*** which is a scanning type.

To reduce the total sampling time of the reflected signals from the underground, the pulse repetition frequency (PRF) is up to 10 MHz. The use of a TEM horn guarantees wide band matching of the antenna of pulse generator.

2. Receiver Front End

Signal conditioning of the scanning antenna are carried out using a Wide Band Low Noise Amplifier (LNA) and an Anti-Aliasing Filter. The LNA has a maximum gain of 40 dB. The received echo pulse signals reflected by the ground structure are amplified up to a level sufficient to convert into digital signals. Direct Analog to Digital (A/D) conversion is used to achieve robust signal detection of echo signals.

3. Scanning Receiver Antenna

The Scanning Receiver Antenna is the most critical subunit of the GPIR. The antenna scans mechanically ***parallel to the earth surface*** and 20-30 cm above the earth surface. The scanning is of ***raster type*** providing scanning of 1x1 m2 horizontal area in the Cartesian coordinate system. A sliding bar carrying out 10 wide band active short size (with respect to the average wavelength of 35 cm) is used to scan the aperture of 1X1 m2. The bar motion is linear with a speed of 0.1-0.2 m/sec. The dipoles are placed in front of a plane reflector to orient the radiation pattern towards the ground medium. The radiation pattern is in compliance with the transmitting antenna and since the transmitter antenna is fixed the scanning antennas sample the electric field distribution on the aperture of 1X1 m2. The switching between the antennas is achieved by using pin-diode switches and activating at a given time 1 out of 10. The use of PRF as high as 10 MHz provides the opportunity to accomplish the acquisition of 10 antenna signals with 64 sequential pulse averaging in a time of 64 µs.

Therefore the dipole bar motion is irrelevant with respect to the signal acquisition time. This also means that much higher scanning speeds can be achieved in recording the aperture fields reaching to an acquisition time of 1-2 seconds. This fact is highly important since this means that the ***radar can operate in a slowly moving car*** and increase drastically the overall inspection time of pipes with the designed and implemented GPIR.

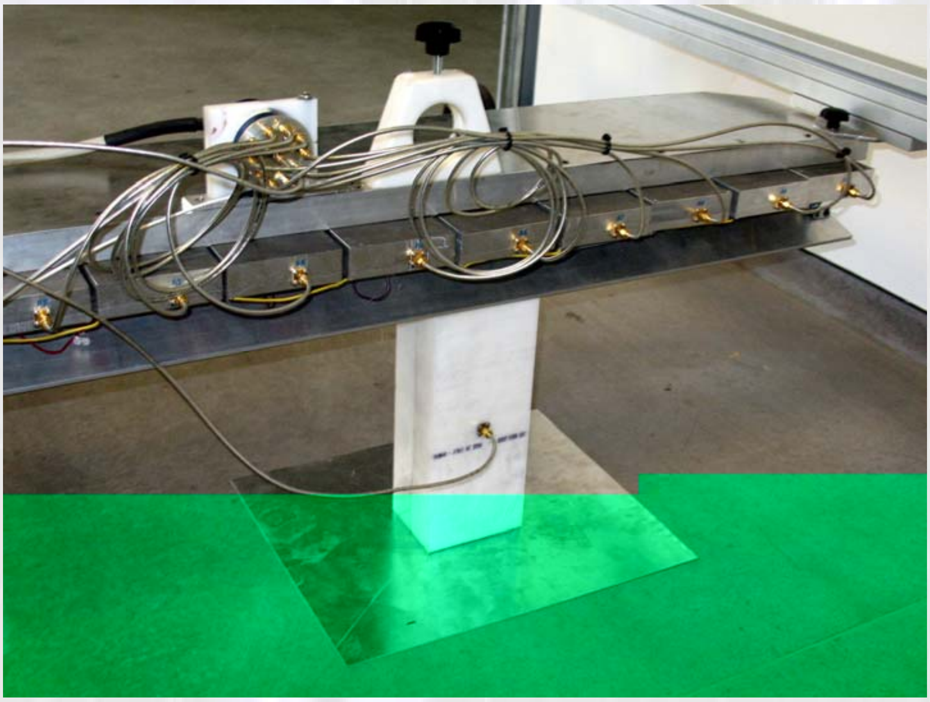

Figure 2. *Photo of the Receiver*

4. Signal Digitizer, Computer and Image Display

Designing and building the signal processing subsystem of the GPIR of the WATERPIPE, needs several future tech-

GPIR system and Subunits Specifications (cont.)

nical facts to be taken into consideration, since the final demonstrator is not be a pure lab based experiment. A series of measurements, outdoors in real conditions and at various terrains, have to be taken during the whole process of design and implementation. So it is crucial for the further progress of the project to design and build a ***digital system***, robust, fast and expandable without forgetting the need for portability and compactness in design.

This digital system has an interface with the Radio Frequency (RF) part of the system, and after sampling all the data provided to that interface, performs digital signal processing of the incoming streams and by using innovative algorithms it finally gives a three dimensional representation of the underlying pipe infrastructure at the scanned area of interest. The heart of the system is a super fast data-acquisition and control subsystem, combined with a processor based platform (more likely a PC) responsible for the post processing and analysis in order to implement the 3D reconstruction of the pipes. So logically the digital system is divided in the two parts. A ***first part*** included in the data acquisition and control module, as well as a ***second part*** that obtains the sampled data from the first part and performs high speed post-processing, are used to calculate the required visual 3D output. The computer where the processing of the recorded echo signals takes place is a 3GHz Pentium. The primary development will focus on the development of imaging software which is based on the Method of Auxiliary Sources (MAS). This method is based on the solution of electromagnetic material media interaction using auxiliary sources within the excited media. The imaging technique is based on correlating the measured time domain data at the 400 points with the Auxiliary Sources assumed to be within the ground media. The number of sources is 400 which provides a sufficient resolution capability. In order to determine the complex amplitudes of the Auxiliary Sources the ***mean square error*** technique is used by comparing the measured data and the Auxiliary Source distribution inside the ground medium. The source field distribution in the volume of interest provides the required images with an expected resolution of 5-10 cm.

5. Inversion Algorithm

Measurement of reflected-scattered wavefront signals from the ground is utilized to compute and present on a computer screen to the users **three dimensional images** of the ground medium. The posed problem is a classical "inverse scattering" problem or "source imaging". The aim is to detect water supply pipe faults with a spatial resolution of 5 cm. It is well known that the exact solution of the "inverse scattering" problem proved to be a very difficult problem because of its essential non-uniqueness nature. The inverse scattering problem is defined as the requirement of computing the unknown complex dielectric constant of the medium (in this case underground medium) by measuring the backscattered waves. The measured quantity is related to the response of the ground medium which according to the Maxwell-Ampere equation is related to the "Polarization Current" of the medium. Two methods are used to develop an imaging algorithm to compute the polarization current based on the measured electric field above the earth surface. The two methods that were implemented are:

a) Fourier Transform Back Projection.

b) Method of Auxiliary Sources.

Figure 3. *Photo of the antenna/receiver and the whole receiving unit by putting 10 separate receiving modules in a row*

Preliminary measurements

The prototype WATERPIPE GPIR system has been implemented and constructed ***since September 2007*** and since then a series of measurements have been carried out, in order to validate its capability to perform the desired imaging and detect the water leaks.

Some ***initial measurements were carried out in a aboratory environment***, by using only dielectric or metallic pipelines/objects, in order to assess the performance of the produced GPIR.

The measurement setup is given in the following figure 5, while the results can be seen in figure 6.

Figure 5. Measurement setup for air and metallic/dielectric objects

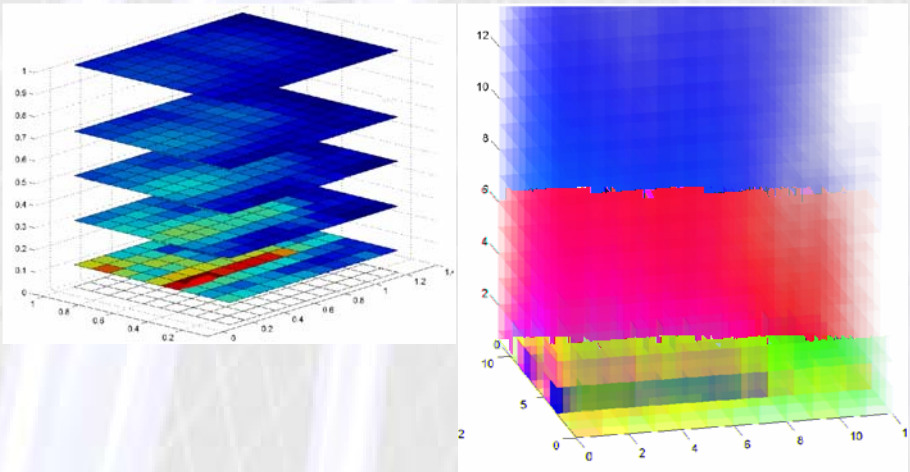

Figure 6. Reconstructed field for the copper tube

Figure 4. Photos of the GPIR System. In the first photo, the User Interface can be discriminated, while at the photo below, the procedure of measurements is presented

Dissemination Activities (Future, Ongoing, Past)

Leakage Technology Conference, ACCADUEO Ferrara Fair, 21st - 22nd May 2008. The Conference was held in Ferrara, Italy 2008 at the premises of ACCADUEO Fair. It was organised by the Italian Water Convention in partnership with Fondazione AMGA and the International Ferrara H2O Fair. The WATERPIPE project and its progress were presented by the project coordinator.

Water Supply and Sanitation Technology Platform 2nd Stakeholder Conference – Brussels, June 2008; WATERPIPE was included into the report presented on the occasion of the 2nd Stakeholder Conference held in Brussels as contribution to the Millennium Development Goal. The running project WATERPIPE is an undertaking whose results are going to fill a current gap leading to practical solutions that can be implemented cost-effectively to provide an improved capability to locate buried infrastructure with accuracy and reliability.

GPR2008 - Birmingham (UK) June 2008 - PipeHawk had a poster site in the Breakout Forum and also on its Stand. Many of the delegates present showed interest in the WATERPIPE concept and those from outside the UK were directed to the WATERPIPE website to register their interest. Across the 3 days approx 40-60 persons from various parts of the world were spoken to regarding the WATERPIPE project.

WATEREXPO 2008 - Zaragoza (SP) September 2008 - the European Commission's Directorate General for Research organised the European water research day aimed at presenting past, on-going and future EU research activities in this field. The meeting was open to all parties interested in EU water research initiatives, particularly those with responsibilities in dissemination and research policy. In that framework contacts between WATERPIPE and project ORFEUS (Optimised Radar to Find Every Utility in the Street) has been established including discussions about the work achievements.

GLOBALWATEREFFICENCY - International Conference and Exhibition – Limassol (Cyprus), November 2008 - The conference is aiming at raising awareness and assisting utilities worldwide to become more efficient and to improve the operational performance of their water supply systems. Presentations and debates on issues such as water governance, water shortage, water efficiency and water conservancy stimulated discussions and exchange of knowledge and experiences. World experts presented on cutting edge successful techniques and methodologies internationally applied as well as on the latest technologies and products used worldwide in managing water efficiently and effectively. WATERPIPE had a special session for the project there.

WATERPIPE web site: The web site of the project is available at the URL www.waterpipe-eu.org.

WATERPIPE Mailing List: IRIDE ACQUA GAS, as responsible party for the project dissemination, is maintaining a WATERPIPE Mailing List of stakeholders and operators in the specific field. All the registered contacts are informed about project progress and results through the WATERPIPE Newsletters. (Contact: Eng. Nicola Bazzurro, WATERPIPE Dissemination Manager, E-mail: nicola.bazzurro@iride-acquagas.it).

WATERPIPE participation in Conferences and Events: in the first project period WATERPIPE partners presented the project at the following international events:

- ***EWRA Conference*** on Water Resources Management New Approaches and Technologies, Chania, Crete (Greece) 14-16 June 2007.
- ***FederUtility Workshop*** "Effective management of water distribution

Dissemination Activities (Future, Ongoing, Past)

systems" held at the University of Perugia in September 2007.

- ***IWA WATERLOSS2007*** Conference, Bucharest, Romania, 23-26 September 2007.
- ***GPR 2008*** held in Birmingham (UK) from 16 to 19 june 2008
- ***WaterExpo*** 2008 Conference, held in Zaragoza in September 2008
- ***Global Water Efficiency Conference 2008*** – International Conference and Exhibition – Limassol (Cyprus), 27-28 november 2008 where Waterpipe had a special session for the project

WATERPIPE CLUSTERING ACTIVITIES WITH OTHER PROJECTS AND NETWORKS Several dissemination activities are addressed to foster initiatives of cluster with other groups. In particular the already established contacts consist of:

- Association and specialists group operating in the specific field (such as Water Loss Task Force of International Water Association, Gruppo Ottimizzazione Acquedotti).
- Project Consortia (ASAP Life project, VESTA-GIS Leonardo project, TRANSCAT project, CITY-NET).
- Thematic Networks and interest groups (TECHWARE Special Interest Group, WATER-GIS Network).
- The project partner Iride Acqua Gas, is a member of the Water Supply and Sanitation Technology Platform (WSSTP), a European Technology Platform (ETP) whose main objective is to ensure that its research addresses the Global Water Agenda by developing appropriate technical solutions to provide effective, sustainable and equitable water and sanitation systems in developing countries. This is essential for the delivery of water and sanitation services to poor people, and is an underlying prerequisite for the attainment of the Millennium Development Goal. In this framework Iride Acqua Gas led the Working Group about Asset Management preparing a report for the EU Commission about research needs and priorities acknowledging the expectations of all the involved stakeholders. The report is also including information about running projects dealing with Asset Management such as WATERPIPE.

EVENTS

- **5th Regional Technology Platform of the European Programme TECHNEAU "Technology for safe drinking water under water scarcity conditions"** Barcelona, December 15th, 2008
http://www.techneau.org/index.php?id=132

- **Water Loss 2009 Conference Cape Town,** South Africa, 26-29 April 2009
www.waterloss2009.com

- **Sustanianbility Live! - Leading the way for a sustainable future,** Birmingham, UK, May 19–21, 2009
www.sustainabilitylive.com

- **IWAGPR2009 - 5th International Workshop on Advanced Ground Penetrating Radar 2009**
Granada, Spain, May 27–29, 2009
http://maxwell.ugr.es

- **Asset Management of Medium and Small Wastewater Utilities**
Specialist Conference
Alexandroupolis, Thrace - Greece, 3 - 4 July 2009
http://iwasam.env.duth.gr

- **2nd International Conference on Water Economics, Statistics and Finance -** Specialist Conference
Alexandroupolis, Thrace - Greece, 3 - 5 July 2009
www.soc.uoc.gr/iwa

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HYDROSAVE	HYDROSAVE (UK)
TECNIC Consulting Engineers	TECNIC (IT)
RISA	RISA Sicherheitsanalysen (DE)
AMS	Advanced Microwave Systems (GR)
ITU	Istanbul Technical University (TR)

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