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CONCLUSION

The ORFEUS consortium has demonstrated a robust and efficient ground penetrating radar system mounted on the tip of a modified, conventional, commercial Horizontal Directional Drilling rig. In addition to extensive laboratry tests it has been shown that such technology can be used operationally in a range of challenging urban environments. Data and power can be delieverd in real time, and the system can be operated without significantly delaying the drilling process. The radar has detected, and avoided, unmapped objects and , has also confirmed the postion of pre mapped objects. In addition, a DIN standard now provides a clear framework for use of such 'drill assisting' technology within a mix of normal utility streetworks. There is also a clear engineering path to making such systems fit for production use.

The ORFEUS consortium would like to acknowledge the valuable support, advice and encouragement of the European Comission in this work which was part of the 7th framework programme.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 308356.

ORFEUS

Operational Radar For Every drill string Under the Street

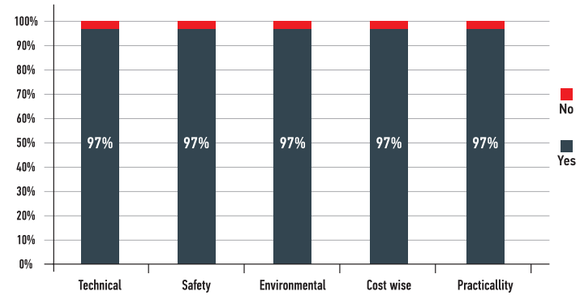
THE ORFEUS PROJECT

"ORFEUS - Operational Radar For Every drill string Under the Street" is a Framework 7 EC-supported project aimed at developing safe, cost effective and fast radar-assisted Horizontal Directional Drilling (HDD) equipment. Operating within the drilling head of HDD systems, the ORFEUS HDD radar provides the real-time obstacle detection needed to increase the safety margins of HDD operations and allow its use in the widest possible range of urban conditions. ilojiuojk

ORFEUS is a full scale demonstration project and is intended to ensure the technical, regulatory and commercial viability of the borehead radar equipment which is achieved through technical refinement, laboratory and field testing in collaboration with end users, and standardisation bodies together with validation of the technical specification and prototype system. The project delivered the full scale practical use of a drill tip radar system in public streets in three European cities, on live sites. Completion of each trial included the provision of a new gas or water main.

ORFEUS commenced in October 2012 and ended in September 2015. It was undertaken by a consortium of 11 organisations from the United Kingdom, Italy, France, Germany, Slovenia, Greece and Ireland. ORFEUS active working partners include Europe's major utilities, drill equipment makers, and advanced survey radar companies.

Thinking about the ORFEUS technology, what are your reactions regarding the benefits?

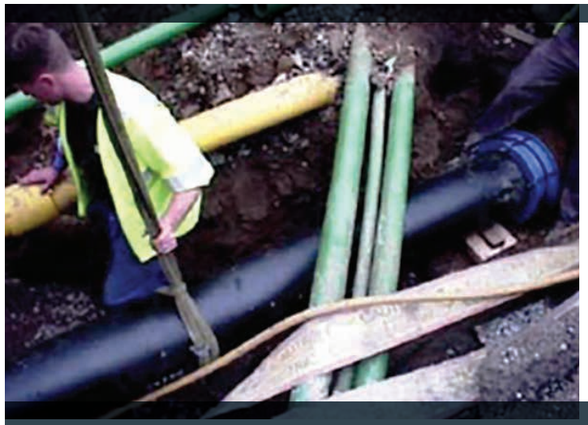


ORFEUS consortium implemented an exploitation survey and published a questionnaire seeking the views of interested parties on the technology developed in the framework of the project. Almost all people who participated in the survey, responded that ORFEUS has technical, safety, environmental, cost-wise and practicability benefits.

www.orfeus.org

HORIZONTAL DIRECTIONAL DRILLING (HDD)

HDD is a "trenchless" method for installing pipes and cables, of various sizes that minimises inconvenience to traffic and people living nearby. This technique is very powerful but, if used in an uncontrolled manner, it can cause significant damage to existing buried infrastructure. Clearly, before this type of system can be used, the operator must have an accurate knowledge of the utilities and other obstructions in its path. Hazards include live power cables, telecommunications lines (wire and fibre optic), steel and plastic gas piping, potable water and sewer lines made from various materials including clay and concrete. Striking one of these assets can be extremely dangerous for the safety of the operators, but can also cause huge economic losses due to the interruption of public services.



The arrangement of existing underground pipes and cables can be complex and their exact position cannot be determined from maps. Surface Ground Probing Radar (GPR) can help but, ideally, a GPR system should be mounted in the drilling-head that continuously scans the soil volume in front of and at the sides to locate all obstacles that can affect the path of the bore in order to avoid collisions and to ensure compliance with statutory clearance requirements between the pipe or cable being laid, and existing utilities. Prior to drilling operations, as much information as possible on the buried infrastructure is gathered from various sources, sometimes including surface operated Ground Probing Radar (GPR).

The performance of such systems is not yet adequate to provide a complete knowledge of obstacles lying in the drill path, although it is anticipated that the proposed new generation of stepped-frequency GPRs will provide a step improvement. Additional information, obtained from a radar located in the drilling-head, should be able to provide real-time indications of obstructions in the drill path so that they may be avoided.

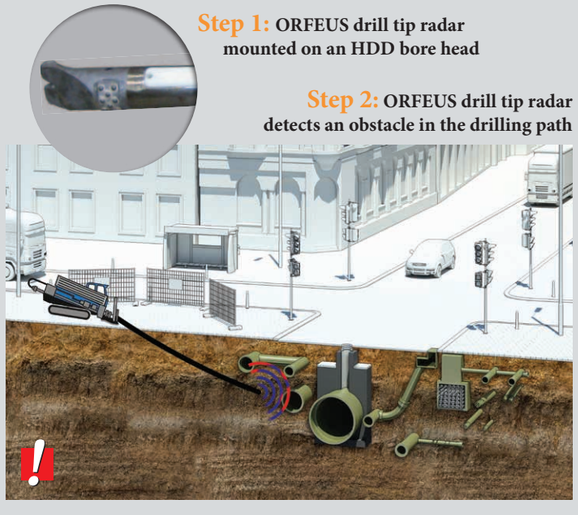
Performance Specification Summary • ORFEUS radar

Detection	Mandatory detection requirements	**i.** Plastic, clay, concrete, polymer concrete and fibre pipes and cables **ii.** Metal and reinforced concrete pipes and cables
	Optional detection requirements	**iii.** Interfaces between different clay soils, humid / wet clay **iv.** Underground cavities **v.** Other buried artificial plant
	Target detection percentage in absorptive soil conditions	Minimum **95%** of all real targets up to **0.5 m** distance from the bore-head must be correctly detected.
	False target generation percentage	False target generation may not exceed **i.** **1%** of the correctly located real targets up to a distance of **0.5 m** from the bore-head in axial direction, **ii.** **1%** of the correctly located real targets up to a distance of **1.0 m** from the bore-head in radial direction.
Classification	Objects to be detected	**i.** Empty pipes and filled pipes **ii.** Electricity and data cables **iii.** Natural and artificial elements (e.g. gravel, rubble, debris, boulders, foundation remains).
	Soil conditions for bore-head radar operations	Bore-head GPR must be usable in all natural and artificial soils types typical for Europe (The geographical scope of ORFEUS is limited to Europe, but there is no reason to suppose that equipment designed to cope with the full range of European conditions would not find application in a global market)
Penetration distances	Penetration on Bore-sight	**i.** Minimum **0.5 metre** **ii.** Preferred **1 metre**
	Penetration in Azimuth	**i.** Minimum **1 metre** **ii.** Preferred **2 metres**
Location accuracy (distance & angle)	Bore-head radar distance measurement accuracy	The accuracy, both in axial and radial directions, must be a minimum of: **i.** **50 mm at 0.50 metres** distance from the bore-head **ii.** **100 mm at 1.00 metres** distance from the bore-head
	Roll angle (measured by a mechanical sensor)	+/-9° (+/- 2.5% of 360°). The roll angle will be measured with reference to a defined angular datum.
Resolution (minimum distance between objects)	The Bore-head GPR shall be able to determine the presence of multiple objects when they are separated by more than **300 millimetres (mm)**.	
Minimum size of objects to be located	Linearly Shaped Objects	Minimum Size **10 mm** across the longest cross section
	Amorphously Shaped Objects	Minimum Size **300 mm** across the longest cross section
Surveying	**a.** The minimum surveying and processing speed must provide real-time results at the operational drilling speed (maximum **0.30 m/sec**. - average operational speed approximately **0.1 m/sec**.) **b.** The roll angle sensor must provide real-time results up to the maximum rotation speed of the drill rig (**200 rpm**)	
Mechanical and environmental	The mechanical and environmental requirements for the bore-head GPR are extremely demanding and, in summary cover the following items: **a.** Material specifications for bore-head, bore-head GPR housing, shock protection and drill rods **b.** Geometrical dimensions and mechanical properties of drilling-head and bore-head GPR housing and drill rods **c.** Power supply from HDD drill rig to bore-head radar **d.** Vibration (shock) protection for bore-head GPR electronics **e.** New geometrical arrangements in the bore head geometry in order to relocate the fluid channel and the existing navigation system. Avoidance of inference between the GPR and the navigation equipment.	
Training level of users	The training and educational level of the users must be such that they are to be able to work reliably and independently. As a minimum, they should fulfil the following requirements: **a.** have, at least, a secondary modern school qualification **b.** have received training in a technical job or have several years of experience in civil engineering, mining, drilling or metal working **c.** have valid driver's license **d.** be able to read, and understand, simple technical drawings and plans (3D imaginative capability). **e.** ideally, have experience in HDD drill rigs (assisting operators, etc.)	
Manufacturing costs	The costs for the production of an operational unit was given in deliverable D6a of Contract n° FP6-2005-Global-4-036856.	

THE ORFEUS RADAR

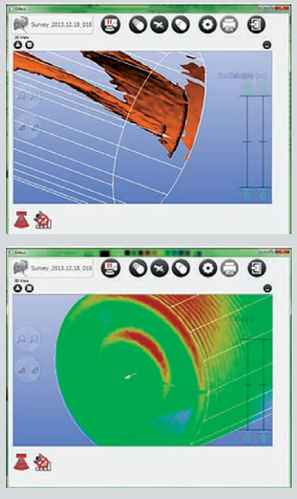
The ORFEUS HDD radar is designed to be a reliable and efficient detection tool that can be mounted within the bore heads of HDD machines. It can detect water pipes, power cables, gas lines, sewers or other obstacles, whether metallic or non-metallic, down to the size of a finger, therefore increasing the safety of HDD installation operations. Depending on soil conditions, it can detect obstacles at ranges of up to 50 centimetres in front of, and around the bore head.

The radar imaging data is transmitted in real-time along the drill string to the surface. These images, after suitable processing, are able to alert the operator to avoid obstacles lying in path of the drill, enabling collision avoidance action to be taken, and to indicate where other buried infrastructure may interfere with the back-reaming and pipe installation operation. Such a capability should enable the use of HDD in situations that are currently regarded as entailing an unacceptable degree of risk, and thus increase business opportunities.

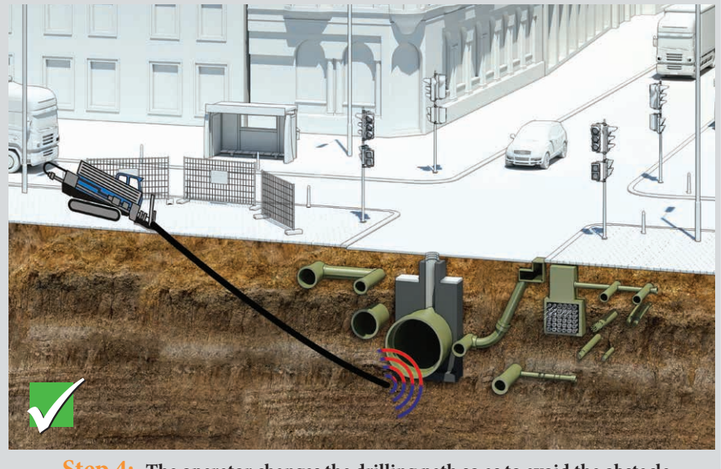


Step 1: **ORFEUS drill tip radar mounted on an HDD bore head**

Step 2: **ORFEUS drill tip radar detects an obstacle in the drilling path**



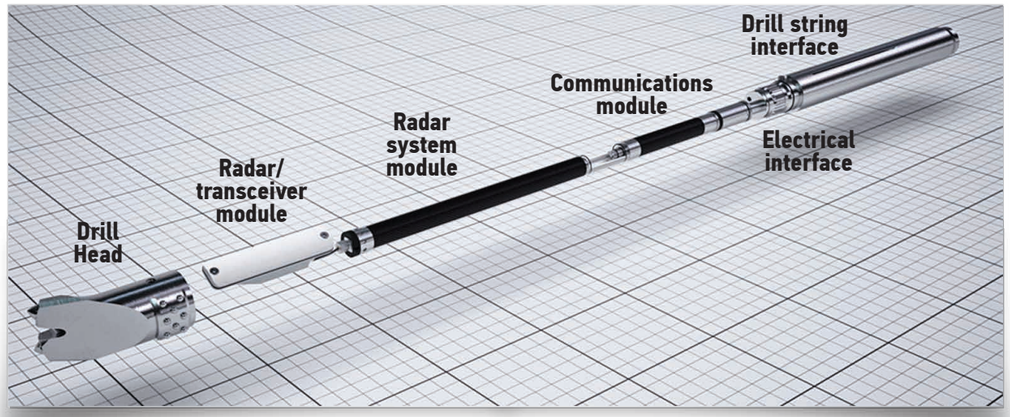
Step 3: **Radar imaging data is transmitted to the drill operator**

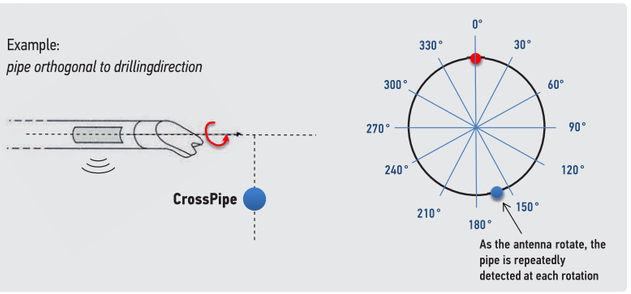


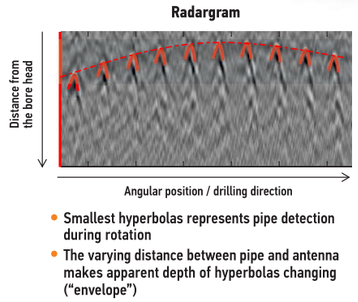
Step 4: **The operator changes the drilling path so as to avoid the obstacle**

THE ORFEUS CONCEPT

The translation of the conceptual arrangement into a physical form involved not only leading edge radar and electronics design, but also attention to mechanical detail in order to meet the demanding environmental requirements of temperature, shock and vibration, and resistance to ingress of water. The conceptual physical implementation details of the system are illustrated below.







THE ORFEUS HARDWARE

Hardware development concerned the key areas of:

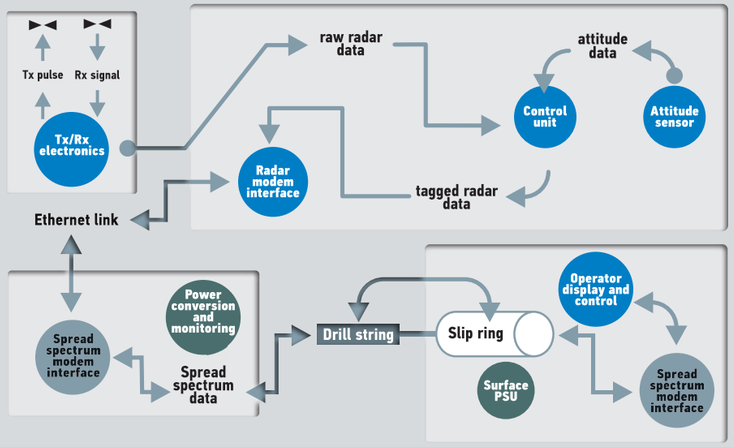
- **antenna design and directional sensing using 3 axis electronic gyroscopes**
- **communications systems utilising spread spectrum technology and a novel drill string interconnection solution to provide a reliable electrical pathway between drill tip and surface for the transmission of radar data and power.**

In addition, some aspects of integration of the subsystems were investigated, particularly the reliability of the electrical interconnection between the individual drill rods as they are inserted into the drill string during pilot hole boring, then removed as the back reaming process proceeds. This work is essential in ensuring that a reliable connection for data and power can be established and maintained during the drilling operation. At the drill head, a communications module connects the drill string transmission line to the radar system. Within the module is a bi-directional high speed data communications link that accepts the raw radar data and encodes it using a robust encryption method so that it may be reliably transmitted through the drill string transmission lines of, over, 100 metres in length. Such a system was evaluated and tested in the ORFEUS 6th Framework project and has now been engineered to withstand the mechanical environment and accept the raw electrical power from the drill string transmission line and process it to power the radar module.

Communications module

SYSTEM FLOW DIAGRAM

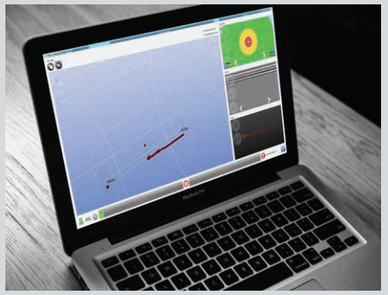
The system concept of ORFEUS involves the generation, then transmission and reception of radar pulses at the drill tip, and its transmission to the surface for aiding the operator in avoiding obstacles affecting the drill path. The management of this process involves not only the production of hardware elements, but their integration into a coherent, functioning, system. The conceptual representation of this process is shown in the system flow diagram.



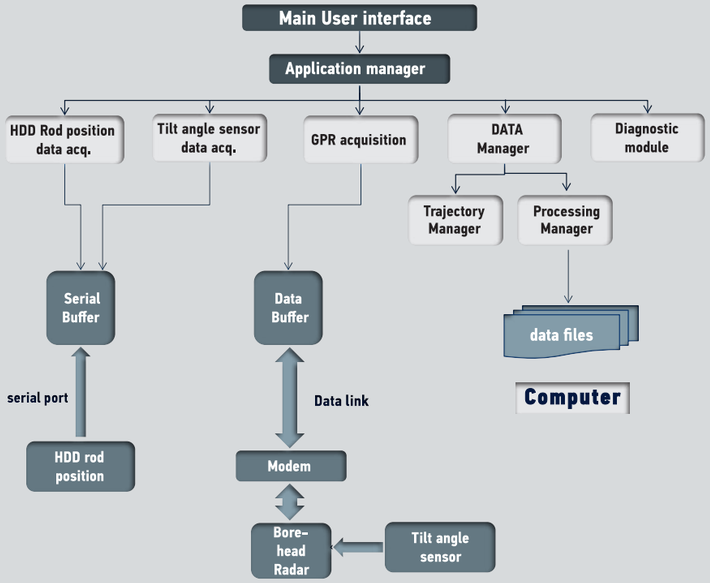
THE ORFEUS SOFTWARE

A data collection and processing software suite was developed that is capable of producing output easily interpretable by the user. Particularly, the following modules were integrated in the software package:

1. **Main User interface,** which includes the radar data display;
2. **Application manager,** that manages all the processes and the data flow from/to the user interface;
3. **Linear position sensor data acquisition**, which manages the position information communicated by the HDD;
4. **Angular position sensor data acquisition** that manages the angular information produced by the tilt angle sensor;
5. **GPR acquisition** which manages the radar data throughput and constitutes the main interface with the radar;
6. **Data Manager** which includes two sub-modules and performs the following features:
   a. Receive the radar data, process and store them in a data file (Processing manager).
   b. Correlate the radar data with the position information (Trajectory manager)
7. **Diagnostic Module** that verifies the proper working of the system by performing a continuous check of the whole hardware.



ORFEUS Real Time Software



Architecture for the software and the links between the different modules

ORFEUS TRIALS

Within the ORFEUS project, demonstration field trials followed the research and development phase and were successfully carried out on operational sites. Activities started in the test site of Tracto Technik in Lennestadt, Germany with a test under controlled conditions of the equipment to commission and calibrate the radar, and verify the communications systems before committing to working with contractors on commercial projects. Three trials were undertaken on operational sites, in Stuttgart(narrow street in suburban area), Paris (dense high rise housing area) and Slovenia (motorway connecting road), where surveys were completed resulting in the successful laying of new pipes and cables, without inconvenience to local traffic.
The performance of the radar, in a range of real operational sites, was investigated during the field trials, but of equal significance was the testing of the provision of power to the underground equipment, and the transmission, to the surface, of the radar data in real-time. Both of these services are delivered, via slip rings and a centre conductor, along the drill string, which also carries the lubricating Bentonite drilling fluid.
Real time radar data and power were successfully transmitted through the automatically-coupled drill rods, using specially developed in-line electrical couplers. In addition to monitoring radar data and images, the system health was also monitored through the performance of the communications and power systems. Operational margins on both data and power that guaranteed good real-time performance were successfully achieved.

LENNESTADT, GERMANY

Trials in the test facility of Tracto-Technik were carried out as a final preparation for the next stage of operational job sites. These trials have demonstrated, and proved, the reliability and robustness of the overall system. This consists of in-cab modem, slip-ring, drill rods, bore-head modem, radar antennas and their electronics including a rotation and tilt sensor.
For the tests, a well-defined bore path was established, with various obstacles, such as aluminium, copper and PVC pipes together with empty and filled holes of various diameters.

This target diversity was designed to test as wide range as possible of the detection capabilities of the ORFEUS radar system. The communication system, including the power supply serving the radar and communications modules, proved reliable in function and operation. Several trials under different conditions, such as distance to target, rotation speed, etc. were carried out and all the obstacles were detected. These trials allowed modifications and improvements to the system before starting work on operational job sites in Paris and Slovenia.

STUTTGART, GERMANY

The first operational job was carried out at the city of Stuttgart with the help and support of the company Leonhard Weiss GmbH & Co. KG. The customer was EnBW (Energie Baden-Würtenberg) and the task was to place an empty PE pipe 160 * 14.6mm at a depth of between 0.9m and 1.60m along a distance of 65m, as a protection for a gas pipe. The soil consisted of marl and the debris of an earlier road. All known obstacles in the ground were identified from the street maps. Although it was a difficult drilling operation, due to hard existing underground obstacles and steering of the bore head was problematic due to the soft nature of some of the ground, the total radar system worked properly and pipes were detected. Planned additional improvements wer made to the communications system and tested in site.

PARIS, FRANCE

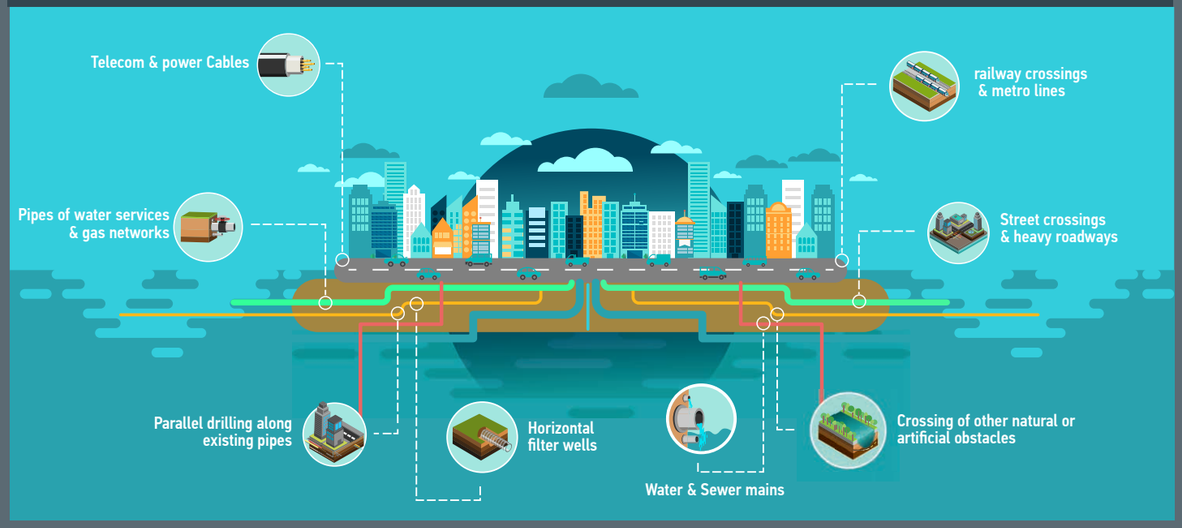
The job site in La Courneuve, Paris was a significant challenge, because of the difficulties of operating in a dense urban environment. Organized by Engie (formally GDF Suez), with the subcontractor BIR, a water pipe of 125 * 12.5mm was installed over a length of 75m. During the Paris trial, the radar detected an undocumented electricity cable in the path of the drill head (verified by excavation), and a collision was avoided. We believe that this may be the first instance of accidental damage being prevented by the use of HDD radar during a commercial drilling operation.

CELJE, SLOVENIA

Under the management of Vilkograd, two tests were carried out in Slovenia on consecutive days. For the first time, a drill rig from a customer was used in place of the Tracto-Technik equipment deployed at the earlier job sites. On the first day, the modified drill rig and radar system was commissioned, and tested, at a prepared job site close to the headquarters of Vilkograd.

Subsequently the system was used to assist in laying a new PEHD water pipe, 160mm diameter, 85 metres in length, in a planned operation near to the motorway-highway exit - AC Dramlje. At this job site it was difficult to find all the known Electrical and optical cables due to the difference in depth between the pilot hole and the buried infrastructure, and the nature of the waterlogged clay ground conditions. At the end of the drill path, however, a cable was detected and obstacles avoided.

ORFEUS APPLICATIONS



STANDARDISATION

Standards planning was an important work package in ORFEUS. The consortium believed that for HDD radar to be adopted an agreed standardised approach to specification and operation is required. After analysing the relevant existing European standards the consortium members decided that the project has the potential to go beyond the original recommendations and decided to create a standard covering this special application of GPR.
ORFEUS agreed a cooperation with DIN (German Standardisation Organisation) and, under their guidance and the leadership of Dr. Mike Farrimond of Wellington Associates, a series of Workshops took place in Berlin resulting in the development of "DIN SPEC 91322 - Bore head radar for horizontal directional drilling; environment, conditions, limitations of use". The work on the Standard was open to all drilling and utility specialists who were consulted and invited to join the ORFEUS consortium members in discussions and document preparation. The standard was published in September 2015 and is available through the DIN website - **www.din.de/en/about-standards/din-spec/current-din-specs** (DIN SPEC 91322)

THE ORFEUS RADAR BENEFITS