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'Détection des fuites dans les réseaux de transport d'eau par radar hyperfréquence'

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General introduction

In modern water supply systems, the amount of water lost through leaks can reach 20% to 30% of the total production. In Wallonia, leaks represent more than 20% of the produced drinkable water. The economic loss, which takes into account the cost of water production as well as damages engendered to buildings and infrastructures, is substantial and the environmental impacts are considerable. Water leak detection is therefore essential regarding to the distribution network management. The most common techniques used to detect water leaks are based on acoustic devices. However, all the current methods show limitations with respect to the background noise, required skills or the configuration underneath the road. Ground-penetrating radar (GPR) is a complementary technology which has raised a substantial interest regarding leak detection. GPR consists in emitting electromagnetic waves and receiving the backscattered fields in order to probe lossy dielectric materials. This technology can be used to detect structures and changes in material properties within the medium. Even if this non-destructive tool appears to be very promising in detecting pipes and leakages of water, some difficulties are often encountered when attempting to detect these ones in field conditions because environmental conditions can be intricate.

In this context, the innovative SENSPORT project aims at developing the GPR capabilities to detect water leaks in water distribution networks and to provide detailed information about underground structures in a non-destructive way. The general objective can be divided into three specific parts. The first one consists in designing an ultra-wideband antenna in order to maximize the information contained in the radar data. The expected radar system will be based on the vector network analyzer (VNA) technology allowing us to perform accurate measurements in the frequency-domain. The second part deals with the signal processing and follows the adaptation and the integration of advanced radar imagery techniques. This step characterizes the qualitative aspect of GPR measurements. The quantitative aspect will be introduced through signal inversion which is used to get additional information about the location of pipe leaks. The last part sets the target of developing a visualization strategy for mobile and web applications which can be used in field conditions. It includes identifying the specific application needs and designing a human-machine interface prototype. To tackle these issues, the objectives mentioned above were divided into 7 main tasks (Figure 1). These ones will be considered as pillars for reporting the scientific findings.

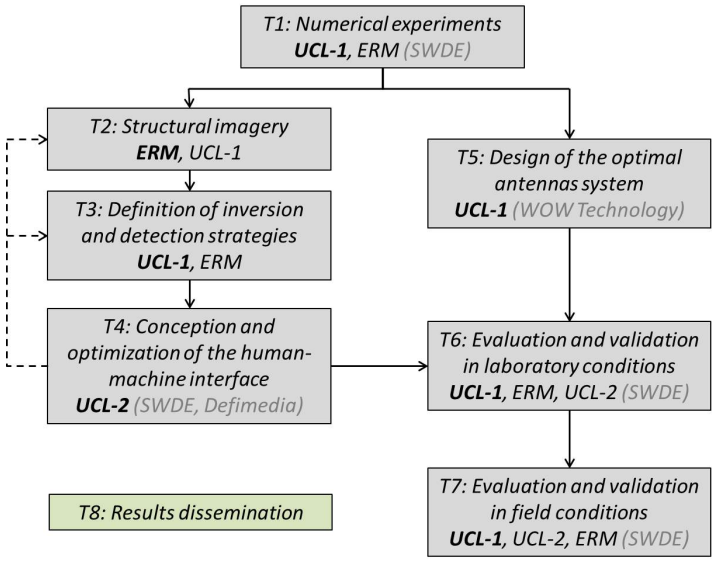


Figure 1: SENSPORT PERT diagram describing the methodology and coordination of tasks (T). UCL-1: Hydrogeophysics laboratory & UCL electric engineering center ; UCL-2 : Louvain Interaction Laboratory from UCL ; ERM : Signal and Image Centre of the ERM. Partners in charge are indicated by bold characters, participants by normal characters and sponsor companies in brackets.

General conclusion

Preliminary field experiments were conducted and particularly highlighted the rational of the project: current GPR techniques are still quite limiting for supporting water leak detection and new tools are needed in a practical context. To tackle this issue, we developed in the framework of the SENSPORT project a general strategy which resorts to the following tools: a 3D visualization interface, a 3D hyperbola detection algorithm, a full-wave inversion procedure and an electromagnetic model which takes advantage of a closed-form solution of Maxwell's equations to describe the antenna-medium system.

The overall, integrated strategy developed for SENSPORT begins by data acquisition. Numerical experiments were conducted in order to investigate different radar-medium configurations and. We also assessed the number of frequencies and the multistatic configurations on the GPR information retrieval capabilities. We demonstrated the possibility of considerably reducing the number of frequencies and, thereby the acquisition and processing time, without affecting the information retrieval capabilities. We also evidenced the great potential of combining multi-static configurations with the reduction of the number of frequencies. Nevertheless, we showed that a general rule regarding the minimum number of frequencies to consider cannot be drawn as it depends on the specific reconstruction problem at hand.

Once the data acquired, they can be visualized directly in 3D by the operator through a web or mobile application. In this work, the data representation was achieved using the Three.js library. The 3D visualization interface is composed of three main elements: the scene containing the radar images represented in 3D, the image of the area where radar data were acquired and the menu containing the visualization functionalities. The different functionalities allow finding the most convenient way to visualize the data.

Unprocessed data very often lead to interpretation issues. Therefore, processing techniques were developed to enhance interpretation. In this study, we removed the antenna effects from GPR images acquired in far-field conditions. We extended it to time-domain radar systems through the development of a correction procedure. The partial removal of antenna effects in near-field conditions also proved to be efficient regarding data visualization enhancement. In addition, different hyperbola detection techniques were developed to facilitate the automatic detection of pipes buried into the subsoil. These techniques also provide a first estimation of the relative permittivity which is itself correlated to the water content of the material. Once these steps achieved, inversion were performed above the pipes in order to retrieve the physical and electromagnetic properties of the upper materials and determine the depth of the pipes. We proposed different inversion strategies based on optimization algorithm or lookup table. Once all the processing steps were achieved, data were sent back to the 3D visualization interface.

The SENSPORT processing chain demonstrated its efficiency, either it is in far- or near-field conditions. We showed it through laboratory experiments conducted with a frequency-domain antenna and a simple medium. Even if some additional developments are still needed to improve the antenna effect removal in near-field conditions, it represents already a great step. Field experiments were also conducted to validate the improvements done in terms of image processing and optimization strategy. To achieve this goal, a new frequency-domain antenna has been designed and constructed. The laboratory tests carried out showed some difficulties with the raw data visualization even if filtered data appeared to really enhance the interpretation. Yet, it is important for the operator to directly visualize the raw data. We therefore decided to conduct the field surveys commercial time-domain systems for which we discovered some limitations in terms of inversions (antenna source instability).

A nice perspective of this work would be the development of a frequency-domain antenna array. It means a higher stability of the antenna system and better performances in terms of inversions. Compared to the previous designed antenna, some improvements including the coupling of the antenna(s) with the medium have to be done. Data visualization could be further improved by the fusion of data coming from antennas operating at different center frequencies. As shown in this work, data fusion removes distortions arising from the different frequency-dependent gains of antennas and provides enhanced images due to the broadening of the spectral bandwidth. Despite the efforts made, some improvements have also to be brought to adequately merge data in near-field conditions.