

# Radar for structural monitoring and assets mapping

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## 1. Introduction

The use of radars in Civil Engineering is well known and there are several applications where it is currently utilised; they include the location of buried objects with Ground Penetrating Radar (GPR) equipment and, more recently, the real-time monitoring of buildings and structures' stability with Interferometric Ground-Based SAR (GB-InSAR) measurements.

The first application is quite old; there are details of such work dating back to 1910, with the first pulsed experiments reported in 1926 when the depths of rock strata were determined by time-of-flight methods.

However, latest achievements in this field have clearly demonstrated that a step-change in the technology is needed; in fact, whilst in the last decade, array-based GPR systems have been developed and released on the market, the remaining barrier to the widespread use of this technology concerns the efficient analysis of very large amount of data. The proposed demonstration will consider the use of advanced hardware and software tools that can help this goal.

GB-InSAR surveying can overcome many of the limitations inherent in traditional kinematic studies by providing autonomous, rapid acquisitions (minutes) of kinematic data at long distances (up to 4 km) and across large areas (several km<sup>2</sup>) from remote locations with displacement accuracy on the order of mm or better.

The use of these remote monitoring systems to detect wall movements in surface mining has emerged in the last ten years as a standard work and safety practice in open-pit mining. Latest developments here concern the use of MMW (MilliMeter Wave) to produce an high-resolution (both range and angular) displacement map of a man-made structure.

## 2. Technical description

Main purpose of GPR data analysis is to extract information from the collected GPR signals and to present it in a meaningful form to the operator; ideally, data interpretation should be easy and quick even for an unexperienced operator.

On this matter, latest innovations as the Tomography that uses migration techniques to produce a more understandable display where the position and the route of the underground assets (e.g. pipes, cables, ducts, etc) are immediately recognisable, help to reduce dramatically the time required for data analysis and to extract the features of interest and to limit "human factor" in data interpretation.

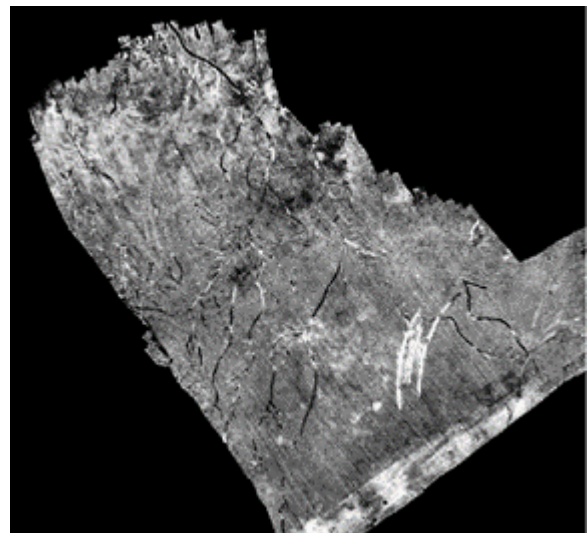


Figure 1: example of a GPR tomography

The quality and the reliability of the results that can be achieved with this tool are strictly related to the effectiveness of the migration algorithm. Migration focuses energy of the hyperbola pattern in its apex; if migration algorithm works correctly tomography will

be focused and pipes are easily recognizable. In order to obtain the best focalization of the energy, it is crucial to get an accurate estimate of the electromagnetic wave propagation velocity.

This is usually estimated with a proper and dedicated tool which is best fitting the shape of the backscattered echo (hyperbola in the radar map) to evaluate the propagation velocity.

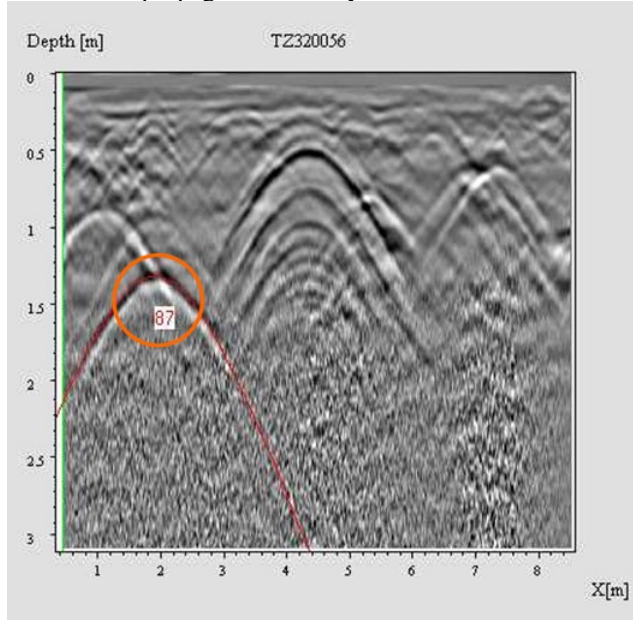


Figure 2: Hyperbolic fitting.

The other argument for this demonstration concerns the use of GB-SAR for monitoring man-made structures. GB-SAR systems synthesize an aperture along azimuth direction by moving the radar head on a rail while transmitting a Frequency Modulated Continuous Wave (FMCW) signal. A range-azimuth image can be focused through proper algorithms, while repeated acquisitions in time of the same scenario can be processed through differential interferometry techniques, obtaining range-azimuth displacements maps.

HYDRA-G is a rotating synthetic aperture MMW radar (Arc SAR): a circular trajectory is used to obtain the synthetic aperture, transmitting and receiving FMCW signals during movement.

The Arc SAR technique together with use of MMW (millimeter-wave) permits a more compact design and a wider angular coverage with respect to traditional linear SAR systems employed for open-pit mine monitoring [1].

These features appear particularly interesting for the monitoring of buildings and structures, especially in critical conditions, where transportability and compactness of the system is necessary, and the short time for mobilization too.



Figure 3: HYDRA-G

### 3. Implementation and results

No matter of the core algorithms implemented in the GPR data processing tool, the analysis of a large amount of signals, requires the implementation of a fast and efficient interfacing between the user and the GPR output.

This can be obtained with the use of powerful graphic processors as well as with a proper design of the user-interface that allows an immersive reality during the post-processing phase.

On this respect, user's expectation concerns the computing time (that should be limited) as well as the possibility to execute re-processing in real-time to evaluating the effect of a custom processing sequence. Last, but not least, a proper 3D visualisation should be available in order to process, analyse and inspect data even from dense array radar systems.

Finally, it is also important to display the georeferenced data in the relevant cartographic context, e.g. by superimposing the GPR data to images of the surveyed areas and permitting an easy management with an intuitive interface with those data (scroll, pinch, spread).

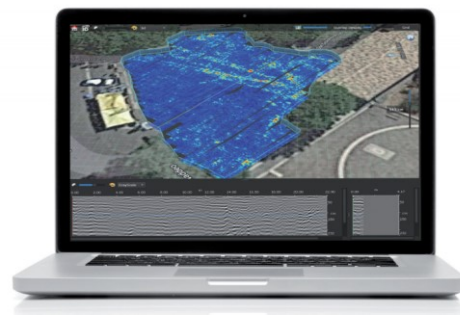


Figure 4: Immersive display of GPR data

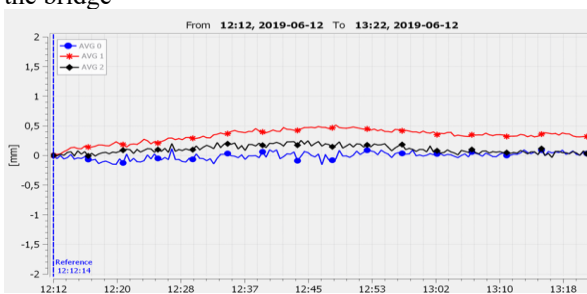
All these software features will be widely described and demonstrated during the conference; also, a live demonstration using a meaningful data set will be executed.

A good example showing the features of HYDRA-G, is the survey executed in the south-eastern part of the town of Gothenburg, in Sweden, a large infrastructure building site was active in summer 2019. One of the main manufact to be built, was a tunnel crossing several portions of the town and interfering with a large part of the existing civil and industrial areas of the urban settlement. In order to verify the possible impact of the many machineries employed during the construction phase, a huge number of monitoring systems (such as total stations) were installed in the surrounding buildings. The traditional geotechnical monitoring devices, very effective and of course reliable, show the limitation of being system to be placed in contact with the physical structure to be surveyed. For this reason, has been asked the deployment of the Hydra G system to be integrated and calibrated against the traditional monitoring device, thus reducing the risk and cost associated with the installation and mobilization phase.



**Figure 4. Hydra G displacement point cloud**

In figure 4, it is shown the superimposing of the point cloud due to the displacement detected by the HYDRA-G on top of the wall face of the bridge and two buildings placed in remote position with respect to the bridge



**Figure 5. Hydra G displacement time series of three points**

Figure 5, instead, illustrates the time series of the group of points selected (black for the bridge wall face,

red and blue for the two buildings) from the point cloud of the three infrastructures object of the monitoring. This shows the displacement (in millimeters, y-axis) of the selected points, during the monitoring time (shown in x-axis).

During the demonstration at the conference, an example of a radar survey dedicated to the monitoring of a civil structure will be executed.

## 4. Conclusions and future developments

The remarkable results in terms of data management and the working environment implementing an immersive reality during the critical post-processing phase of GPR data, have led to an unmatched increase of productivity. The analysis of an area up to 30.000 sqm requires now just a working day; 10 years ago an area of 3800 sqm could be analysed in one day [2], so the benefit is evident.

Also, the use of MMW GB-InSAR has been demonstrated to compete in terms of results and reliability with the standard geotechnical monitoring devices, solving the limitation of being system to be placed in contact with the physical structure to be surveyed.

## 5. Acknowledgments

This work has been completed according to the objectives of the GEOFIT Project.

GEOFIT focuses on the demonstration of innovative geothermal based retrofitting solutions for buildings; a task for the project concerns the deployment and integration of advanced methods of worksite inspection, including ground research and building structural monitoring.

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## 6. References

- [1] M. Cecchetti, M. Rossi, F. Coppi, "Performance evaluation of a new MMW Arc SAR system for underground deformation monitoring," Proc. SPIE 10788, Active and Passive Microwave Remote Sensing for Environmental Monitoring II, 107880B (9 October 2018); doi: 10.1117/12.2323828.
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