Ground Penetrating Radar

Ultra-wideband radars for improvised explosive devices and landmine detection

For last two decades Ultra-Wideband Ground Penetrating Radars seemed to be a useful tool for detection and classification of landmines and improvised explosive devices (IEDs). However limitations of radar technology considerably limited operational use of these radars. Recent research at TU Delft solves the bottleneck problems.

Author: D. Sc. Alexander Yarovoy, Faculty EEMCS, TU Delft

Landmine problem
Land contamination with landmines and all types of unexploded ammunition (usually called unexploded ordnance or UXO) appeared to be a world-wide problem with enormous humanitarian impact. Sixty-seven countries are affected by landmines (see figure 1), however reliable estimates of the worldwide area affected are not readily available. Estimates of the number of mines laid vary widely from 50 to 150 million. In mid-90s humanitarian demining has been worldwide recognized as an important topic on the political agenda. According to the Land Mine Ban Treaty (Ottawa, 1997) all stockpiles of mines should be destroyed within four years and all minefields lifted in ten years. For many countries the deadline is 2009.

Despite of political willingness of world community to solve the landmine problem in a short term, the situation on the ground does not change fast. The probing sticks, dogs and electromagnetic induction metal detectors [Mine Action

Equipment: Study of Global Operational Needs, 2002]. Unfortunately, the metal detector has problems like insufficient detection depth and high false alarm rate when detecting anti-personnel mines with low metal content. As an example of metal detector performance can be used statistics of humanitarian demining in Cambodia between 1992 and 1998: only 0.3% of 200 millions excavated by deminers items were antipersonnel mines or UXO [J. McDonald et al., Alternatives for landmine detection, Rand Corporation, 2003, pg.xvi]. Absence of reliable high-tech tools for humanitarian demining results in a fact that demining remains a dangerous, slow, and costly process. For military demining there are some tools (e.g. mechanical flails or rollers) to trigger mines and cause their explosion. However such mechanical demining does not meet high standards of safety of the cleared area established by UN [area is declared as safe if 99.6% of all mines are cleared]. Without development of new demining tools, which should drastically reduce false alarm rate and improve detectability, the minefield goal of the Ottawa treaty is unattainable within the ten-year timescale.

Clearance of improvised explosive devices (IED) faces in principal the same problems as humanitarian demining. The conventional approach of using only electromagnetic induction metal detectors frequently generates a large number of false alarms due to the presence of shrapnel and other metal debris.

UWB radar sensors
During last decade a lot of attention has been paid to develop a ultra-wideband (UWB) radar sensor for landmine/IED detection. Such a radar sensor (sometimes called Ground Penetrating Radar or GPR) is in some sense similar to an ultrasonic scanner in a hospital. However in the contrary to the ultrasonic scanner the radar uses electromagnetic and not ultrasonic waves. The radar radiates a short pulse into the ground. This pulse propagates in the ground and scatters from all inhomogeneities. The scattered field is received and processed by the radar. As a result of the processing the radar provides a 3D image of the subsurface. Ultra-wide operational bandwidth of the radar is needed to deal with electromagnetic pulses with duration of about 1 nanosecond or less.

It has been found that in many field conditions GPR sensor can detect almost all antitank and antipersonnel mines as well as UXO and IED. Furthermore, GPR can support classification of detected objects and drastically reduce false alarm rate during demining operations. Finally, standoff radar systems might play some role in detection of landmine fields and in this way contribute to the reduction of suspected mine areas.

However, the available in the last century GPR technology was not sufficient to combine fast ground survey with classification of detected objects. As a result numerous attempts of operational use of GPR sensors had limited success and so far GPR sensor is operationally used only as a secondary sensor in hand-held landmine detection systems.

Research at TU Delft
For more than 15 years the International Research Centre for Telecommunications and Radar (IRCTR) at Delft University of Technology performs research in the area of UWB technology, which has started from time domain antenna measurements. Due to its large social importance the problem of humanitarian demining became the focal point of UWB-related research in IRCTR at the very end of previous century. To overcome limitations of available GPR technology a broad-scale research program has been started which included investigation of ground properties, the development of concepts for advanced GPR front-ends, the research on improved GPR-antennas and arrays, research on new methods of subsurface imaging based on interferometry and polarimetry and development of feature-based detection and identification techniques.

The research has been performed in a number of projects with different partners among them the Laboratory of Electromagnetic Research, the Centre for Applied Geophysics [both TU Delft] and TNO Defence, Security and Safety. Together with above-mentioned Dutch research groups collaboration with international partners such as RTI/MIPT [Moscow, Russia], Tomsk State Technical University [Tomsk, Russia], Tohoku University (Sendai, Japan), GeoZondas (Vilnius, Lithuania), TU Bandung and LIPI [both Indonesia] has been established.

Combination of fundamental and applied research, concentration of efforts on solving particular problems and use of non-standard approaches finally resulted in development of so-called mini-array GPR sensor. This radar sensor was developed along a new approach, which comprises a novel design for the antenna array (figure 2), digital beam-forming and selection of a special waveform fired by the pulse.

Figure 2: Novel antenna system of the mini-array GPR
generator. Via electronic footprint steering the system can perform imaging of the scene avoiding mechanical scanning (in one direction).

Using digital delays in all receive channels the radar is capable to produce a near-field focusing in the cross-scan direction. Migration of the data acquired along the direction of a scan is used for the focusing in the scan direction. As a result a near-field focusing of the acquired data is achieved and a 3D image of the area under investigation is produced. The dedicated feature-based detection and classification algorithms allow reliable detection of all inhomogeneities, which possess certain features (e.g., certain shape and size, dielectric permittivity, etc.).

Novel system design allowed to achieve a breakthrough in GPR technology, namely to increase surface scanning speed from a few km/h to 130 km/h allowing use of the radar not only at a vehicle-based but also helicopter-based platforms. The built demonstrator has been successfully tested within a multi-sensor suit developed by TNO Defence, Security and Safety (figures 3 and 4).

**Perspectives**

The achieved technological breakthrough allows realization of an operational prototype for landmine and IED detection within a period of two to three years. Accumulated in IRCTR knowledge allow for development of GPR array-based sensors with a swath from 40 centimeters till maximum 6 meters and operational scanning speed up to 130 km/h. Realization of the complete multi-sensor system requires cooperation with other Dutch knowledge institutes such as above-mentioned groups in TU Delft and TNO Defence, Security and Safety.

Figure 3: Mini-array GPR (covered with a light-blue case) within multi-sensor suit of TNO Defence, Security and Safety

Figure 4: 3D subsurface image of five anti-personnel mines