3D borehole radar technology development aims to transform drilling applications

3D borehole radar technology introduced recently by Dutch company T&A RADAR is said to represent a breakthrough in ground penetration radar technology enabling improved soil exploration at greater depths and more difficult environments. In this article Ronald van Waard, the company's R&D project leader, explains some of the background to the technology which took four years to develop (in co-operation with TNO-FEL and the National Aerospace Laboratory) and could have global application for all forms of drilling including oil and gas exploration.

The geophysical community has for a long time been looking for surface ground penetrating radar technology with greater penetration depths. Increases in transmitting power and better antenna design have improved a great deal, but environmental regulation, among other things, has limited the use of more powerful transmitters and this approach to improving equipment is likely to become more difficult in the future. So the logical step was to try to bring ground penetrating radar closer to the position of the targets of interest by lowering it into a single open or (plastic) cased borehole.

This posed its own technical problems, such as enclosing the equipment in a narrow tube. In the past many manufacturers and research institutes have achieved this. Until now the equipment had some common disadvantages. For example, hardly any were directional and most were based on some sort of analogue measurement, digitized a considerable distance away from the antennas, thus imposing limitations on data throughput, performance and extensible. Also transporting (strong and weak) analogue radar signals over cables longer than 100 m is a challenge, while shorter cables are less problematic but not suitable for certain applications.

The solution to these limitations was to build a directional ground penetrating radar with down-hole transmitting signal generation, at the transmitting side, and down-hole sampling, at the receiving side. All the equipment would have to fit in a single borehole with acceptable borehole dimensions, and transport information digitally using widely available technology to make it highly extensible.

Unlike currently available equipment, the 3D BHR technique can determine the exact position of an object from within one single borehole. Depending on soil composition, it is possible to survey an area up to 15 m from the borehole. Previously, the maximum diameter of the surveyable area was roughly 1 m in similar conditions. The 3D BHR is equipped with the hardware and software to cope with the large data throughput from 3D measurements, as well as the orientation and full 3D positioning during the measurements. This concept is believed to be the first transmitter and receiver in one system capable of surveying soil construction from within one borehole with the range and accuracy to determine the exact position of objects from within that borehole.

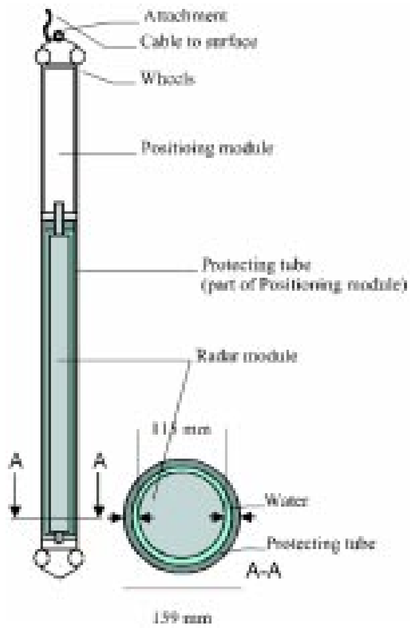
Description

One of the advanced aspects of the 3D BHR system is the bi-static antenna set-up. The two identical antennas are directional. Their design combines directional sensitivity with energy bundling by placing rotating reflectors behind the dipole and filling the space in between with a permissive medium. It is these reflectors that provide the directional sensitivity and the energy bundling to the 3D BHR.

The physical constrains that apply to all ground penetrating radars dictate that directivity is easier to achieve with higher frequencies. The problem is that these frequencies have less penetration. So during development it was clear that there was always a need for compromise guaranteeing penetration and directionality at the same time. This determined the size of the antennas, which were optimized for 100 MHz, as well as the outside diameter of the 3D BHR.

Other criteria included an overall modular and robust design, to create a simple but flexible tool. This led to a complete separation of orientation and positioning from the actual radar measurements, which are carried out by one cylindrical radar module containing the two antennas and all the electronics. This module, on its own, does not determine the positioning or orientation of the unit and is not designed to withstand larger pressures, mechanical stress or extreme temperatures. A positioning module, containing motor and positioning detectors and able to house the whole radar module, was built to overcome the problem. The positioning module protects the radar module from the hostile environment encountered down a borehole. Its modular design made it easier to develop the equipment in co-operation with the research bureau TNO-FEL and the National Aerospace Laboratory.

Another important aspect was the data throughput. Common ground penetrating radar equipment can sample in a wide frequency band at high frequencies (more than 1 GHz) and gather 16-bit words using a technique called sub-sampling. This means that for every sample to be gathered, a pulse is sent, and for that particular sample a very accurate delay is determined at which only that particular sample is taken. Virtually every sampling frequency can be chosen, as long as the delay can be determined accurately, but this also means reducing the measuring speed to the pulse repletion time. From tests, it became clear that this sub-sampling could not be used if all the data was going to be gathered within a reasonable time frame. This resulted in the development of a new A/D hardware, which was able to sample in real time at 600 MHz. This came at a price, as there are very few wide band A/D converters that sample at that frequency, being the length of the 8-bit words. The difficulty working with these 8-bit words is that the sensitivity range where one wants to measure has to be very well controlled. The advantage is that the repeatability is improved, thanks to pulse stability (decreasing pulse repetition time), much less power consumption and a considerable increase in measuring speed of at least 500-fold. This meant that we had to deal with a data throughput which had increased about 250-fold compared with conventional sub-sampling.



Orientation is determined using angle encoders for the internal angle, caused by the motor, and sensitive low velocity gyroscopes for the external angle, caused by the rotation of the 3D BHR in the borehole. Neither of these orientation methods are affected by the electromagnetic fields present during normal operation. However, as gyroscopes cannot perform absolute angle measurements, they had to be calibrated, which can be done visually by the operator or automatically using a high-speed magnetometer if circumstances allow it.

Measurements

The 3D BHR is connected to a console

at the surface by a power and transmission cable. After starting up the system and calibration, the unit is lowered into the borehole to its deepest point. The measurement is started while pulling up the radar module, which is rotating at a constant speed, collecting data in a helix. Meanwhile, radar and orientation data is transmitted to the console where the data is stored. As soon as the measurements are completed, the radar data is merged with the orientation data, at which point processing can be done to obtain a three-dimensional image of the borehole surroundings.

Equipment

T&A Radar has already built and tested the first prototype of the 3D BHR. It can be positioned and used at every possible orientation. Positioning and orientation is designed to maintain accuracy up to 5° rotation in every direction and up to 5 cm along the axis of the unit.

First prototype characteristics (future versions will be lighter and smaller):

- Length: 4.4 m with a diameter of 15.9 cm
- Weight: 225 kg (without cable)
- Pressure: 3 bar

- Power consumption: approximate 200 W downhole
- Data transmission: Ethernet LAN (10 Mbps) using TCP/IP
- Capacity: 1 m borehole in 1 to 10 minutes, depending on the accuracy
- Length cable: 30 m (but this can easily be extended up to several hundred metres)
- Build up time: 15 min
- Number of operators: 2
- Transport: 5 pieces of down-hole equipment (longest piece 2.25 m)

Usage

Four important uses for the 3D BHR system are:

- Detection of unexploded ordnance. The application of the technology for detection surveys of unexploded ordnance will reduce, in most cases, the amount of drillings required. This can lead to important cost reductions and improved quality. To detect deep unexploded ordnance in an area of one hectare it is usual to perform up to 10 000 drillings in order to lower a magnetometer. When using the 3D BHR technology, 400 drillings are enough to map an area of this size. This is a reduction of over 95%. With a penetration of 10 m around the borehole, only 100 drillings are required. Consequently the use of the 3D Borehole could provide cost reductions of between 60 and 80%.
- Tunnel track survey. The drilling of tunnels is currently a blind process. Most drilling companies are unaware of what is directly in front of the tunnel boring machine (TBM). By using 3D BHR technology they will be promptly informed of the nature of any obstacles or geological boundaries in front of the TBM, enabling these to be taken into account if required. Technical and financial risks should be decreased whilst improving the safety of such operations.
- Jetgrout or concrete injections. Concrete foundations are used for an increasing number of underground infrastructure projects, such as the construction of the North-South underground in Amsterdam. These so called jetgrout injections consolidate the subsoil and decrease risks of subsidence at the surface. No practical and useful techniques existed to calculate the diameter of injected columns, so it has been impossible to conclude whether the foundations provide enough stability. The diameter of the column can now be determined on-line by integrating 3D BHR technology into the injection lance. The Amsterdam tunnel drilling project intends to apply this method.
- Oil and gas reservoirs. An oil or drilling company can use 3D BHR as a logging instrument to collect survey information for an area up to 15 m in diameter of the borehole, helping to make an accurate evaluation of the contents and volume of the oil and/or gas reservoir.

Future developments

It is expected that the unit's dimensions, mainly length, weight and power consumption, will decrease, while penetration is maintained and accuracy increased. Processing and the operating system, controlling all operations, will improve and possibly become (partially) embedded in the whole 3D BHR system.

Indian contract boosts Paradigm's Asia Pacific ambitions

Paradigm Geophysical says that its geophysical data processing and analysis service facility in Perth, Australia, which services the Asia Pacific region, has significantly expanded its capacity to meet demand for oil and gas exploration and reservoir development in the region.

David Cox, Paradigm's vice president for the Asia Pacific Region, said that the company's processing capacity had already been increased by 170% but would expand by a further 40% in the third quarter. Paradigm Geophysical's Asia Pacific office has been boosted by a contract to process new 3D and 2D seismic data from offshore India on behalf of one of the successful applicants in the recent bidding round conducted by the Indian Government under its New Exploration Licensing Policy (NELP). The data is part of nine offshore blocks recently awarded under the NELP to Indian and foreign companies, on both the east and west coasts of India, in shallow and deep waters.

The first phase of the seismic data processing project has begun in Paradigm's service centre in Perth involving time processing through to pre-stack time migration, and is expected to extend to advanced AVO analysis and pre-stack depth migration. Paradigm is building on a turnkey contract in India completed last year. That contract called for the provision of an advanced seismic data and interpretation centre in Dehradun for India's Oil and Natural Gas Company (ONGC).