HIGH RANGE RESOLUTION DIRECTIONAL BOREHOLE RADAR FOR 3-D FRACTURE DELINEATION

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1. INTRODUCTION

Subsurface sensing is important in engineering and scientific applications. Among many geophysical subsurface sensing methodologies, Ground Penetrating Radar (GPR) is unique in its fast data acquisition, and high accuracy resolution. However, electromagnetic wave penetration into geophysical material is normally poorer than other methods such as seismic wave exploration, and borehole radar is one of the solutions for deep survey by using drilled holes by GPR. We are investigating directional borehole radar method for 3-D subsurface imaging.

2. CONVENTIONAL BOREHOLE RADAR TECHNOLOGY

Range distance to targets can be shorten by using boreholes, however, normally not many boreholes are available for measurements, and we need to obtain as much subsurface information as possible from a single borehole. Consequently, we use lower frequencies compared to normal surface GPR, in order to achieve a longer penetration range. Most current borehole radar systems use frequencies below 100MHz, which can achieve a penetration range of about 20-50 m in crystalline rock. The diameter of boreholes available for borehole radar is usually less than 15 cm, so the outer diameter of the waterproof downhole sonde of a borehole radar is limited by this value. Most borehole radars use long thin dipole antennas for the transmitter and the receiver because the geometrical structure fits the shape of the thin downhole sonde. The diameter of the borehole is typically less than 1/10 of the wavelength of the radar signal. Therefore, the radiation pattern of most borehole radar antennas is considered omni-directional around the borehole axis.

In many engineering applications, however, we need to know the three-dimentional orientation of subsurface targets, and directional borehole radar is therefore of interest. In order to achieve directivity in a thin borehole, a few different approaches have been proposed. A dipole antenna with a reflector has a directional radiation pattern around a borehole axis. However, the antennas must be mechanically rotated, which makes the system complicated. This type of antenna can be practically used only when the diameter of the borehole is relatively large because small separation between the antenna and a metallic reflector reduces the antenna efficiency. The eccentric location of a dipole antenna can break the axial symmetry, and can achieve a directional radiation pattern, without the reduction of antenna efficiency. However, the radiation pattern is still almost omni-directional .

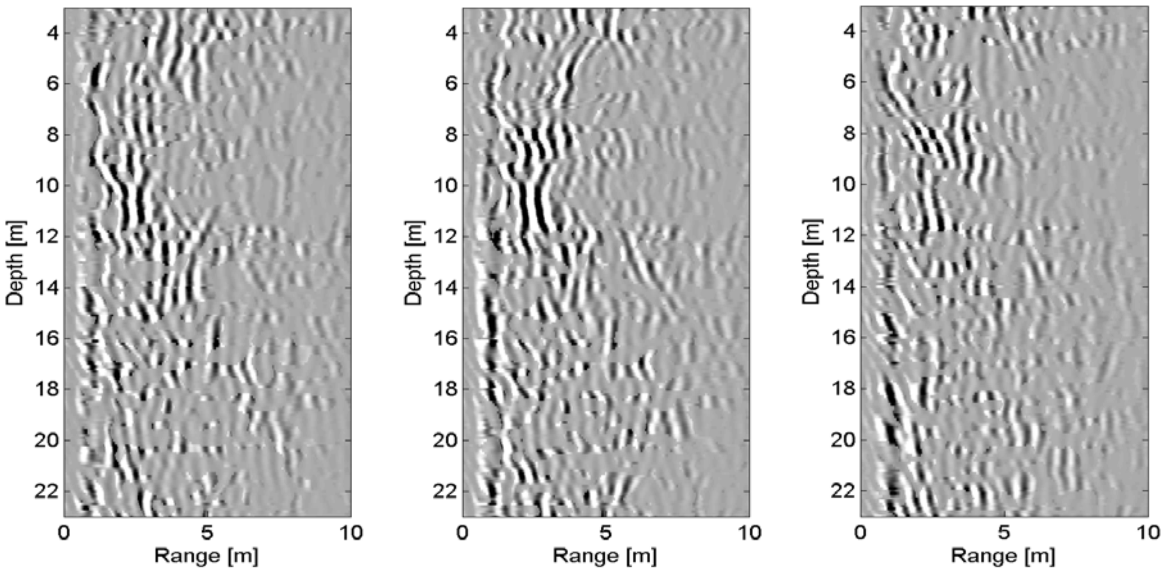
3. DIRECTIONAL BOREHOLE RADAR

We developed an array type borehole radar system using an optical electric field sensor[1]. We confirmed the performance of the phase detection ability in laboratory experiments. Thanks to the passive optical electric field sensors, the array antennas in a think down hole sonde has minimum metal parts, and the directional performance of the radar can be improved compared to conventional array antennas by using active electric circuits. The experimental results showed that when signal to noise ratio is sufficient, our radar system can determine a small phase difference, which is enough for the azimuth angle estimation in real measurement conditions. Mutual coupling which distorts phase information was observed at frequencies around 200 MHz. However, phase is not affected below 150MHz.

4. 3D SUBSURFACE IMAGING

Cross-hole and a single-hole borehole radar measurements were carried out at the Kamishi test site, Japan. From the cross-hole measurement, we have determined that the peak power of the system is at around 70 MHz in the boreholes. By using the single-hole radar data, we estimated the azimuth orientation of the subsurface fractures. A simple algorithm based on the synthesized rotating radiation pattern of the array antenna can be used for azimuth orientation estimation. By combination of the new hardware system and the algorithm we achieved an estimation of the reflected wave azimuth angle accurate to about 30 degrees. Then we also conducted single –hole and cross-hole test in Korea[2].

Fig.1 (a)-(c) show the directional vertical subsurface profiles obtained at Kamaishi test site, Japan. There are many separated subsurface fractures in this particular location, and we can see changes in profiles in Fig.1. This indicates that we are looking fractures in different azimuth angles.



(a) South (b) E30S (c)E30N

Fig.1 Directional vertical profile obtained by our directional borehhooe radar

5. CONCLUSION

A new directional borehole radar using optical electric field sensors has been completed. A new algorithm for directional imaging was also proposed. Then we demonstrated 3D subsurface fracture imaging by a newly developed directional borehole radar. 3D orientation of subsurface fractures could be imaged.

6. REFERENCES

[1] Motoyuki Sato, Takuya Takayama [2007], A Novel Directional Borehole Radar System using Optical Electric Field Sensors, IEEE Transactions on Geoscience and Remote Sensing, Vol.45, no.8, pp. 2529-2535.
[2] Takuya Takayama, Motoyuki Sato [2007] , A Novel Direction-Finding Algorithm for Directional Borehole Radar, IEEE Transactions on Geoscience and Remote Sensing, Vol.45, no.8, pp.2520-2528.