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GPR Signal Processing with Geography Adaptive Scanning using Vector Radar for Antipersonal Landmine Detection

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Abstract: Ground Penetrating Radar (GPR) is a promising sensor for landmine detection, however there are two major problems to overcome. One is the rough ground surface. The other problem is the distance between the antennas of GPR. It remains irremovable clutters on a sub-surface image output from GPR by first problem. Geography adaptive scanning is useful to image objects beneath rough ground surface. Second problem makes larger the nonlinearity of the relationship between the time for propagation and the depth of a buried object, imaging the small objects such as an antipersonnel landmine closer to the antennas. In this paper, we modify Kirchhoff migration so as to account for not only the variation of position of the sensor head, but also the antennas alignment of the vector radar. The validity of this method is discussed through application to the signals acquired in experiments.

Keywords: information processing and signal analysis, landmine detection, GPR, migration

1. Introduction

Over seventy million landmines are said to be untreated. So, it is big social problem for safety life environment after the conflict. Currently, there are two major methods of landmine detection. One is search using metal detector and other is search using an exploratory needle, however, those method have problems. An exploratory needle method requires operator to come close to landmine and to contact physically with land mine. So, dangerousness of exploratory needle method can not be denied. A metal detector is one of the most major sensors for a current humanitarian demining. It has been relied for many years because there is no better sensor in viewpoint of cost and simplicity. It hardly misses an antipersonnel landmine (APM) in shallow subsurface. However, it has a serious problem. It responses all objects including metal, even though most of them are entirely safe. This feature of metal detector brings tremendous false alarms, and it reduces efficiency of demining.

On the other hand, GPR (Ground Penetrating Radar) is a sensor expected as an alternative of metal detector or support device of it(Shimoi, N, 2002), (Orifici, D, 2004). GPR system measures the response time of electromagnetic wave reflected by buried object, and it is originally used for archeological digging, detection of underground pipe and detection of lack in reinforced concrete. GPR can seek plastic landmine unlike in the case of metal detector. And GPR can obtain the information concerned with buried objects such as depth and figuration. It is considered extremely effective for landmine detection, and some researchers have been studied(Feng, X., Sato, M. 2004), (Daniels, D. J., 2004).

Though GPR is expected high performance as a sensor system for landmine detection, there are many problems under stand-alone operation. At first (1) decrement of an electromagnetic wave becomes large, and performance turns worse by a water state of the soil where a mine is laid underground. In addition, (2) reliability of a detection result deteriorates when operation is conducted with non-homogeneous soil. As a more serious problem, (3) when there is the irregularities or a slant in a ground surface, they are projected onto an image of the underground, and it becomes difficult to distinguish a shallow undergrounding object. For the first problem, it can be moderated influence by choosing the electromagnetic wave frequency, which is hard to be absorbed water. And combination with a metal detector is effective on the second problem. However, because the last problem is a reliability fall at the depth that synergy with a metal detector can expect, it cannot be overlooked. As influence of rough ground surface, (i) electromagnetic wave reflection by the small irregularities on ground
surface and (ii) heterogeneity of velocity field generated by fluctuation of air layers with inclination of ground surface, are included.

For the enhancement of mine detection system, we have studied about methodology that vector type ground penetrating radar with three antenna elements (Kimura, N. et al., 1992), (Murasawa, K. et al., 1992) is adaptively scanned for ground surface (Fukuda, T. et al., 2005), (Yabushita, H., 2005), (Hasegawa, Y. et al, 2004), (Yabushita, H. et al. 2004), (Hasegawa, Y. et al, 2005). Above mentioned problems are improved by geography adaptive scanning. Because, when antenna plane faces ground surface in parallelism with constant distance, (i) effect of reflection by the small irregularities on ground surface can be reduced on computer, and (ii) velocity field can be calculated correctly on computer by keeping air layers constant. On the other hand, location error of antennas in migration, which is vanishingly small when target area is enough deep, is not mentioned. When measuring shallow area with electromagnetic wave, position of antennas should be considered. Especially, because manipulator changes position of antennas on geography adaptive scanning method, effect of location error becomes bigger.

In this paper, effectiveness of geography adaptive scanning method for searching buried object with rough ground condition is mentioned. And signal processing method, which is obtained by extension of pre-stack migration considering the feature of vector radar system, is proposed. Finally, effectiveness of vector radar system and proposed signal processing method is confirmed by experiment.

2. Ground Penetrating Radar and its signal processing

In this section, fundamental principle of GPR and outline of signal processing is introduced. It is needed to explain effectiveness of our approach.

2.1. Fundamental principle of GPR

GPR (Ground Penetrating Radar) works as follow: A transmitting antenna radiates electromagnetic waves in the underground, and a receiving antenna receives reflected waves from objects under the ground, and finally radar system estimates structure under the ground based on electromagnetic contrasts. Multistatic GPR have several measure types such as common source, common receiver, common midpoint, common offset (Daniels, D. J., 2004). And in this paper, common offset measurement using vector GPR is adopted. It is difficult to judge buried objects by just displaying a time-series signal of GPR to a graph. Therefore, a time-series signal is expressed by colored line, and a chronological order section is expressed by arranging colored line in horizontal direction. Otherwise, distribution of reflection strength of under ground space is calculated by signal processing, and it is displayed by a cross-section surface and volume rendering (Daniels, D. J., 2004). In this paper, it is a research purpose to make reflection strength distribution on three-dimensional space which can make distinguish of undergrounding objects easy. An operator will select appropriate visualization method from time cross-section surface, level cross-section surface and perpendicular cross-section surface depending on the situation.

Fig. 1. Appearance of vector radar.

Fig. 2. Transmission mode of vector radar.

Fig. 3. Appearance of manipulation system.

2.2. Signal Processing

Signal processing of GPR consists of some processes. Firstly, a reflection from a ground surface and coupling between transmission and reception antennas are removed by a method of average signal subtraction. As a
result, reflected signal from underground object is amplified. Secondly, those signals are changed to three-dimensional distribution map of reflection rate by using deconvolution, scattering matrix process, inverse Fourier transform, time offset adjustment, normal move out correction, migration and recovery of gain. In those processes, migration process requires special consideration at adaptive scanning with vector GPR. In this paper, we focused on enhancement of the migration process.

2.3. Vector GPR

Figure 1 shows vector GPR adopted for this research. This GPR system have three antenna elements and realize measurement with three polarization characteristic at one time as shown in Fig. 2. It has ability to be able to calculate a measurement signal in arbitrary polarization characteristics by using scattering matrix process for acquired measurement signals (Kimura, N. et al., 1992), (Murasawa, K. et al., 1992).

This GPR system is wide range step frequency type and measures not time-domain signal but frequency-domain signal: original signal is function of frequency. A time-domain signal is calculated using inverse Fourier transform.

\[
\phi(x, y, z, \frac{\partial R}{\partial}, m, t) = \text{IFT} \{\psi(x, y, z, \frac{\partial R}{\partial}, m, f)\}
\]

Field of reflected wave expressed with \(\phi(x, y, z, \frac{\partial R}{\partial}, m, t)\) is measured with raw data: where \([x, y, z]_S^T, \frac{\partial R}{\partial}\) are center position of antenna and rotation matrix of sensor heads, \(m\) is polarization mode, \(t\) time between transmitting and receiving. Relationship of sensor head frame \(S\), base frame \(B\), sensing point and imaging potin is illustrated in Fig. 3. In our case, \(z, \frac{\partial R}{\partial}\) are restricted by functional surface with argument \(x, y\): this surface is calculated based on measured ground surface.

\[
\frac{\partial R}{\partial} = \frac{\partial R}{\partial} (x, y).
\]

\[
z = z_p(x, y).
\]

Therefore, measurement signal is expressed as \(\phi(x, y, m, t)\) with only independent argument.

3. Time-domain migration with adaptive scanning

Normally, \(\phi(x, y, t)\) distribution of reflection rate in three-dimensional space is acquired by scanning ground surface. However, because GPR antenna does not have so strong directivity, when there is a small object in space \(P_o = (x_o, y_o, z_o)\), effect of small object in \(\phi(x, y, t)\) distribution appears with spatially-extended condition. In other words, when reflected wave is simply converted to distance from antenna, high resolution images is not to be acquired. The process that \(\phi(x, y, t)\) original data is changed to \(\phi(x, y, t)\) distribution of reflection rate in three-dimensional space is called "migration".

3.1. Kirchhoff migration

Firstly, the condition that a radar which have transmitting antenna and receiving one on same point scans on horizontal plane is considered. More specifically, following equations are able to be approved.

\[
z = 0.
\]

\[
\frac{\partial R}{\partial} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}.
\]

Then, \(\phi(x_s, y_s, t)\) is calculated as follows,

\[
\phi(x_s, y_s, t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \psi(x, y, z, \frac{\partial R}{\partial}, m, f) e^{i2\pi \frac{\partial R}{\partial} r} df.
\]

\[
\sigma(x, y, z) = \frac{1}{2\pi} \left( \int_{0}^{2\pi} \cos^2 \phi \int_{0}^{\pi} \frac{dx dy}{r^2} \right) dx dy.
\]
\( r = \sqrt{(x-x_3)^2 + (y-y_3)^2 + z^2} \).  
\( \cos \theta = -z/r \).
\( t_p = 2r/v \).

where, \( \sigma(x, y, z) \) is amplitude reconstructed on coordinate system \([x, y, z]^T\). Eq. (7) is called Kirchhoff integration and fundamental equation of time-domain migration process. This calculation realizes reconstruction the reflection rate of point \((x, y, z)\) by collecting effect distributed on hyperboloidal surface. In other words, this process corresponds to determine the strength of a correlation between measured signal and ideal signal which might be observed on the assumption that there is a punctate reflective object on \((x, y, z)\) (Sato, M. et al, 2004), (Schneider, W. A., 1978).

3.2. Migration with geography adaptive scanning with vector GPR

Kirchhoff migration on preceding section is assumed flat surface scanning as manipulation of radar system. Originally, it can not be adopted for signals obtained by geography adaptive scanning. Therefore, Kirchhoff migration considering geography adaptive scanning is proposed. And, when distance between antenna and buried object is short, effect of distance between transmitting antenna and receiving antenna can not be neglected : this effect is neglected in Eq. (7). Therefore, prestack migration method is applied to solve this problem. However, if each method is used independently, enhanced image is not able to be obtain. In this paper, methodology which combine idea of geography adaptive scanning Kirchhoff migration and one of prestack migration, is extended for vector GPR.

3.2.1. Kirchhoff migration with geography adaptive scanning

Kirchhoff migration in previous section is conducted with assumption that height of radar \( z_g(x, y) \) stays constant.

When geography adaptive scanning is conducted, height of each antenna should be considered in migration process with Eq. (7) in order to obtain chiseled image (Hasegawa, Y. et al, 2004), (Yabushita, H. et al. 2004).

\[ \sigma(x, y, z) = \frac{1}{2\pi} \int \frac{\cos \theta \phi(x, y, z; t_p)}{r^2} dx dy dz. \]  
\( \phi(x, y, z; t_p) = \phi(p) \).

\( p = [x, y, z]^T \), \( p_s = [x_s, y_s, z_s(x_s, y_s)]^T \).

\( r = \|p_s - p\| \).

\( \cos \theta = n_g(x, y) \cdot (p_s - p)/r \).

\( t_p = 2r/v \).

where, \( n_g(x, y) \) is unit normal vector of ground surface, and it have relation with \( \hat{R} \) : rotation matrix of sensor : as described in following equation.

\[ n_g(x, y) = \hat{R}(x, y) \cdot [0, 0, 1]^T \]

It considers the effect by height and posture of antenna for calculation of both of directional coefficient \( \cos \theta \) and travel time \( t_p \) in those equations.

3.2.2. Prestack Kirchhoff migration

Migration explained in previous subsection is conducted with assumption that transmitting antenna and receiving antenna are on the same point. Many radar systems have transmitting antenna and receiving antenna are on the different point. Traveling time of electromagnetic wave is not proportional to depth of buried object on such radar system. When radar system which have antenna distance \( h \) measures buried object located immediately below with depth \( d \), \( t_p \) : traveling time of electromagnetic wave is described in Eq. (17) (Sato, M., 2002).

\[ t_p = \frac{2}{v} \sqrt{d^2 + (h/2)^2} = \frac{2}{v} d \sqrt{1 + (h/2d)^2}. \]  

Virtual antenna is set on center of transmitting and receiving antenna for the purpose of avoiding this problem as shown in Fig. 4. Signal \( \phi(t_p) = \phi(t_p) \) is acquired with assumption that electromagnetic wave is transmitted and received by virtual antenna, and migration is conducted using \( \phi \) with Eq. (7) (Feng, X., Sato, M., 2004).

\( \hat{t}_p \) : more precise traveling time considering distance of antennas: is calculated from \( \hat{t}_p \),traveling time base on virtual antenna assumption: using normal moveout correction with Eq. (17).

![Fig. 5. Geometries of Antennae and reflector for NMO (normal moveout) correction.](image-url)
The mentioned problems (Feng, X., Sato, M., 2004). Prestack migration is suitable for the imaging a mine like object which is small and buried close to ground surface.

3.2.3. Kirchhoff migration with vector GPR

In section 3.2.1 and 3.2.2, geography adaptive scanning and distance of antennas are considered at migration process respectively. However, both of them are needed for enhancement of migration when geography adaptive scanning is conducted with vector GPR. Those methods have common idea to obtain traveling time with accuracy. Therefore, traveling time of electromagnetic wave from transmitting antenna to receiving antenna is calculated according to position of antennas, and migration process specialized for geography adaptive scanning with vector GPR is formulated.

Figure 4 shows coordinate system of GPR. Here, position of focused point under ground is indicated as \( p = [x, y, z]^T \), and center position of three antennas at measurement is \( p_S = [x_S, y_S, z_S, (x_S, y_S)]^T \). Then, reflection rate \( \sigma(x, y, z) \) is expressed by Eq. (21).

\[
\sigma(x, y, z) = \frac{1}{2\pi} \int \int \cos ^2 h / 2 \cdot \rho_{\text{CMP}}(x_S, y_S, h_t) \ dx_S dy_S dh.
\]

Kirchhoff integral is changed in Eq. (20), in order to interweave precise traveling time when electromagnetic wave passes through marked points toward antenna. And, stacking process is conducted at one time by integrating along with \( h \) : displacement on direction between the antennas. It is known that precise imaging is realized by those methods in order to avoid above mentioned problems (Feng, X., Sato, M., 2004). Prestack migration is suitable for the imaging a mine like object which is small and buried close to ground surface.
summed and normalized. This intensity correction is derived by traveling trajectory and directivity of the antennas.

The procedure to average signals on each polarization mode corresponds to abstract isotropic reflective component (Kimura, N. et al. 1992). So, it is possible to treat this procedure that both of migration and polar processing is conducted coinstantaneously by Eq. (21).

4. Experiments

4.1. Experimental environment

Measurement experiment using vector GPR for detection of imitation mine is conducted to confirm the effectiveness of proposed reconstruction algorithm of image. A buried object used for experiment is plastic imitation of Type 72 antipersonnel landmine made in China (φ78mm×40mm). Appearance of buried object is shown in Fig. 8. Dry sand with 3% water content proportion is set in large bucket, and its surface is formed with inclined plane. Then, imitation of mine is buried horizontally with condition that its upper side is same depth for ground surface. Firstly, Ground for experiment after burial of imitation of mine is shown in Fig. 9. And, Secondly, ground surface data measured by laser range finder is shown in Fig. 10. Finally, appearance of geography adaptive scanning manipulated by PA10 manipulator is shown in Fig. 11.
4.2. Flat scanning and geography adaptive scanning
Firstly, the effectiveness of geography adaptive scanning against for flat surface is described. Migration process expressed by equation (21) is conducted for GPR signal obtained under the both condition of flat scanning and geography adaptive scanning as shown in Fig. 12. Each horizontal slice is shown in Fig. 13. Figure 13(a) is for flat scanning, and figure 13(b) is for geography adaptive scanning. It is difficult to distinguish a buried object in horizontal slice (a) by the influence of reflection wave from ground surface. On the other hand, a form of circular buried object can be found in horizontal slice (b).

![Fig. 12. Radar scanning methods](image)

**Flat scanning**  **Geography adaptive scanning**

![Fig. 13. Horizontally sliced images reconstructed from the signals acquired by level scanning and geography adaptive scanning](image)

(a) Flat scanning  (b) Geography adaptive scanning

4.3. Effect of polarization process with vector GPR
Next, the effect to integral three polarized electromagnetic signals obtained by vector GPR is explained. Figure 14 shows result of conduction of proposed migration process for signal obtained by geography adaptive scanning. Each horizontal slice obtained with single polarization mode skipping addition concerned with m in Eq. (21) are shown in Fig. 14 (a), (b) and (c). On the other hand, a cross section obtained in accordance with Eq. (21) inclusive integration of three polarization modes is shown in Fig. 14 (d). All horizontal slices are in the depth where imitation mine is buried.

It can be confirmed that there is a buried object in the position where actually imitation mine is buried (x=200mm, y=175mm), even if in the case where migration process is conducted with single polarization mode. However, image of buried object is distorted by polarization charactoristic of ground surface. Especially, distortion is remarkable in the case with m = 2. And, image of clutter on upper side of screen is more clear than that of imitation mine. On the other hand, image which is obtained by integrating three images of individual polarization mode have distinct circular object share. Furthermore, clutter is lower reduced than that in the case of single polarization mode.

![Fig. 14. Horizontally sliced images processed with various polar modes](image)

(a)Kirchhoff migration  (b)Kirchhoff migration modified for vector radar

4.4. Migration specified for vector GPR
In this subsection, the effect of migration considering positions of transmitting and receiving antennas on generation proper image of underground is confirmed. Image calculated with assumption that all transmitting and receiving antennas are on center of GPR is shown in Fig. 15(a). In this case, migration process is conducted for each single polarization mode using Eq. (11), and then those are integrated. And image calculated by proposed method is shown in Fig. 15(b). Proposed method realizes distinct image. However, image which does not have strong reaction compared with proposed one is generated with assumption that transmitting antenna and receiving one are on same position. Because, center of reaction for buried object on each image are misaligned by the influence of displacement of the antennas.

![Fig. 15. Horizontally sliced images processed with and without consideration of the alignment of antennas in the sensor head](image)

(a)Kirchhoff migration with NMO correction  (b)Kirchhoff migration modified for vector radar

5. Conclusion
Vector GPR system with geography adaptive scanning has ability to seek antipersonal landmine buried in gound, which have rough surface. Because both influence of rough ground can be reduced. One is the reflection wave by small irregularities on ground surface. Other is heterogeneity of velocity field generated by fluctuation of air layers. However, signal processing also has to be
improved considering location of antenna elements. Therefore, in this paper, signal processing method specialized for vector GPR based on prestack migration is proposed. Finally, effectiveness of vector radar system and proposed signal processing method was confirmed by experiment.

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References

Daniels, D. J. (2004). Ground-Penetrating Radar, 2nd Edition, IEE-UK, ISBN13-978-0863413605, U.K.

Feng, X., Sato, M. (2004). Pre-stack migration applied to GPR for landmine detection, Inverse Problems, Vol. 20, No. 6, (Dec. 2004), s90–s115, ISSN-0266-5611

Fukuda, T. et al., (2005). Land mine detection algorithm using Ultra-Wide Band GPR, Systems And Human Science: For Safety, Security And Dependability -Selected Papers of the 1st International Symposium SSR2003, Osaka, Japan, November 2003-, pp.275–286, Elsevier Science Ltd, ISBN-13-978-0444518132, Japan

Hasegawa, Y. et al., (2004). Landmine Detection Algorithm using UWB GPR, Proceedings of SICE System Integration Division Annual Conference (SI2004), pp. 1029-1030, 2004, Ibaraki, Japan

Hasegawa, Y. et al., (2005). Automatic Extraction for Mine Suspects from GPR, Proceedings of of the IARP International workshop on Robotics and Mechanical Assistance in Humanitarian Demining (HUDEM2005), pp. 27-32, Tokyo, Japan

Kimura, N. et al. (1992). Development of Radar for Investigation of Buried Objects (First Report), Proceedings of National Convention of the Institute of Electrical Engineers of Japan 1992, pp. P1-64 – P1-65, 1992

Murasawa, K. et al. (1992). Development of Radar for Investigation of Buried Objects (Second Report), Proceedings of National Convention of the Institute of Electrical Engineers of Japan 1992, pp. P1-66 – P1-67, 1992

Orifici, D. (2004). A Guide to Mine Action, Geneva International Centre for Humanitarian Demining (GICHD), http://www.gichd.ch/, Switzerland

Sato, M., (2002). Subsurface Imaging by Ground Penetrating Radar, IEICE Transactions, Vol.J85-C, No.7, (2002), pp.520–530

Sato, M. et al (2004). Subsurface Investigation with Electromagnetic Wave, The textbook for public recurrent education named “Subsurface Investigation with Electromagnetic Wave” held in Tohoku Univ., 2004

Schneider, W. A. (1978). Integral Formulation for Migration in Two and Three Dimensions, Geophysics Vol.43, No.1, (1978), pp.49–76, ISSN-0016-8033

Shimoi, N. (2002). Technology for detecting and clearing LANDMINES, Morikita Shuppan Co., Ltd., ISBN-13-978-4627945517, Japan

Yabushita, H. et al. (2004). Ground Adaptive Manipulation of GPR and Image Reconstruction for Landmine Detection, Proceedings of SICE System Integration Division Annual Conference (SI2004), pp. 1029-1030, 2004, Ibaraki, Japan

Yabushita, H., (2005). Land mine detection algorithm using Ultra-Wide Band GPR, Systems And Human Science: For Safety, Security And Dependability -Selected Papers of the 1st International Symposium SSR2003, Osaka, Japan, November 2003-, pp.245–257, Elsevier Science Ltd, ISBN-13-978-0444518132, Japan

Zhou, H., Sato, M., and Liu, H., (2005). P Migration velocity analysis and prestack migration of common-transmitter GPR data, IEEE Transactions on Geoscience and Remote Sensing, vol.43, (2005), pp.86-91