MVA'90 IAPR Workshop on Machine Vision Applications Nov. 28-30,1990, Tokyo

RADAR IMAGE PROCESSING FOR LOCATING UNDERGROUND LINEAR OBJECTS

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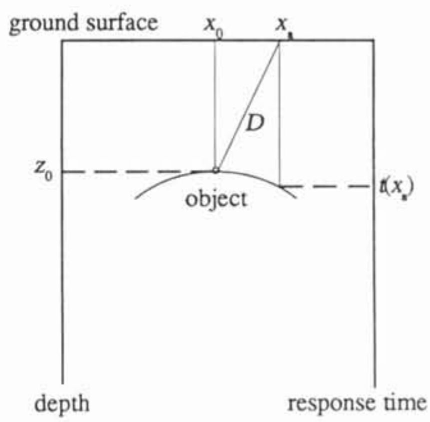
ABSTRACT

This paper presents an image processing method for locating underground linear objects using ground-probing radar data. One of the problems when using ground-probing radars is how to know the microwave propagation velocity in the ground of the test area. The proposed method employs the Hough transform of the edge contours of pulse echoes in a radar image, which appear as hyperbolas, whose shape contains the velocity information. The method uses two types of Hough transformation. The first one transforms each edge position and orientation to a straight line on the transform plane that has the horizontal location of the object and the square of velocity as its two axes to rapidly estimate the velocity. The second one, which transforms each edge position to a parabola on the transform plane having the horizontal location of the object and the square of echo response time as its two axes, realizes aperture synthesis to give a focused echo source. A preliminary experiment confirms accurate depth measurement for multiple parallel pipes lying close toghether.

1. Introduction

Underground linear object location is a very important technology for the construction of social infrastructures such as telephone/electricity cables and gas/water mains. Ground probing radars have been developed for this purpose(e.g.,[1]). Ground probing radars, however, have a significant problem in that the velocity of radar wave propagation in the ground is generally unknown. This problem was overcome by the development of image processing technique that used the property that buried linear objects present hyperbolic radar images[2][3]. Both techniques used the Hough transform to rapidly determine object depths with accuracy. This paper extends method[3] to multiple pipe-like objects. The extended method determines the depth of the outermost objects and the propagation velocities of the ground adjacent to said objects.



x_s: horizontal location of the antenna
x_0: horizontal location of the object
z_0: depth of the object

Fig.1. Geometry of an underground object.

2. Property of radar images

Suppose that a pair of antennas transmitting and receiving radio pulses are shifted in the same direction over the ground to obtain a two-dimensional radar image, whose two orthogonal axes indicate the horizontal location along the surface and the propagation time of the pulse echoes, respectively.

Here, let x_0 and z_0 respectively be the coordinates of the horizontal location and the depth of the linear object which lies perpendicular to the cross section expressed by the radar image (see Fig.1). This paper first examines the case for a single object for simplicity. If the distance between the transmitter and the receiver is small compared to the depth of the object, then the distance, D, from the object to the antennas' centroid, whose horizontal location is x_s, is represented by the following equation.

$$D=\sqrt{(x_s-x_0)^2+z_0^2} \qquad (1)$$

The response time, $t(x_a)$, of a pulse echo is given by the following equation, where v is the microwave propagation velocity in the ground.

$$t(x_a)=2D/v=\sqrt{4(x_a-x_0)^2/v^2+t_0^2}, \quad (2)$$

where $t_0=2z_0/v$.
Equation (2) shows that the pulse echoes form a hyperbolic radar image (see also Fig.1). Then, velocity estimation can be realized by analyzing the shape of the hyperbola.

3. Procedure flow

The proposed method consists of five stages as described briefly below.

(1)Preprocessing

The original radar image is averaged by local windows in order to reduce the effect of noise.

(2)Edge contour extraction

Echoes are detected as edges in the image. Detected edge contours are segmented into groups each of which is regarded to belong to one point source.

(3)Propagation velocity estimation

Microwave propagation velocity is estimated by the Hough transform of segmented edge contours. This transform also gives the object's horizontal location.

(4)Aperture synthesis

If the above Hough transform yields poor results, aperture synthesis processing is executed to improve them.

(5)Object locating

Using the velocity and the locations for individual edge segments, the real object location can be estimated for the outermost objects.

4. Extraction of edge contours

Rise edges of pulse echoes are detected by level-crossings along each data line, and edge contours are given as connected rise edges traversing lines. The following processes are performed on the edge contours.

(1) Smoothing of edge contours

Because of noise present in the radar data, edge positions may be fluctuated. By averaging neighboring edge positions, edge contours are smoothed.

(2) Segmentation of edge contours

An edge contour originating from a single reflective point source in the ground appears to be hyperbolic. Thus, its edge contour can be segmented into a set of unimodal portions. Here, we must take into account that some interference occurrs between ajacent unimodal portions with multiple pipes. Thus the unimodal portions are further divided into pairs of monotonous increasing (left-hand side) and decreasing (right-hand side) portions, which are termed 'edge segments' in this paper, and sometimes refered as a left and a right edge segment. Figure 2 shows an example of edge segments.

(3) Selection of significant edge segments

Underground man-made linear objects give more intense pulse echoes than other natural sources such as pebbles, earth layers, and water tables. To select significant edge segments, the method employs two predefined thresholds for the horizontal displacement range of the edge segment and the aspect ratio of the encasing rectangle of the edge segment. Only significant edge segments undergo Hough transformation.

Figure 3(a) is the binary representation of an experimental radar image, which was taken by an experimental

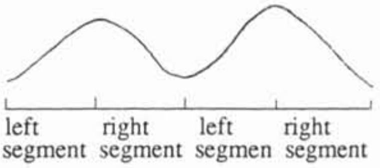
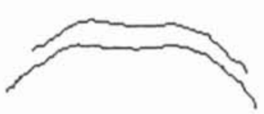


Fig.2. Segmentation of edge contours.

(a) The binary representation of a radar image.



(b) Significant edge segments.

Fig.3. The experimental radar image and its significant edge segments.

radar set whose transmitting antenna was driven by a 2nsec pulse generator. The original radar data consists of 177-by-300 points which represents a horizontal traverse of 352cm and a 40nsec response time range. Figure 3(b) is the result of significant edge segment extraction.

5. Velocity estimation by the Hough transform

The 1st derivative(the slope), $g(x_s)$, of an edge at coordinates, $(x_s,t(x_s))$, is given from Eq.(2) as

$$g(x_s)=\mathrm{d}t(x_s)/\mathrm{d}x_s=4(x_s-x_0)/v^2t(x_s). \quad (3)$$

If we define $u\equiv v^2/4$, Eq.(3) is rewritten as

$$x_0=-g(x_s)t(x_s)u+x_s. \quad (4)$$

Ideally, Eq.(4) is true for each edge data set $\{x_s,t(x_s),g(x_s)\}$, but noise and measurement errors cause deviations from the equation. Then, let a two-dimensional Hough transform plane (x_h,u_h) be set, and possible point sets given by Eq.(5) for the respective edge data sets be plotted on the plane (i.e., draw lines).

$$x_h=-g(x_s)t(x_s)u_h+x_s \quad (5)$$

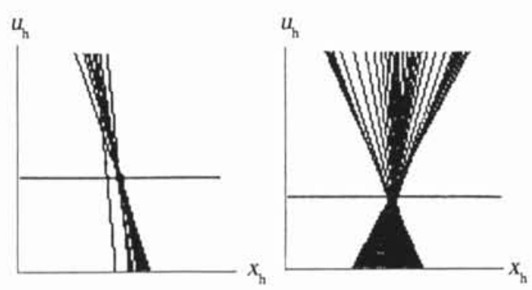
Only lines that satisfy the following condition are drawn on the Hough transform plane. The second derivative of $t(x_s)$ is given from Eq.(3) as

$$h(x_s)=\mathrm{d}g(x_s)/\mathrm{d}x_s=1/ut(x_s)-g(x_s)^2/t(x_s). \quad (6)$$

Reordering, we have

$$u=1/\{h(x_s)t(x_s)+g(x_s)^2\}. \quad (7)$$

We cannot obtain u directly from Eq.(7) because



(a) (b)

Fig.4. The Hough transform plane (I).

$t(x_s)$, $g(x_s)$, and $h(x_s)$ may contain errors. However, we can guess the range of u by physical conditions. Thus by setting lower and upper limits, u_{lower} and u_{upper}, we have the criterion.

If $u_{lower}<u<u_{upper}$, then draw a line given by Eq.(4) on the Hough transform plane.

After drawing lines for a segment, the peak is located, and its coordinates (x_h,u_h) represent x_0 and u.

Figure 4(a) shows a right edge segment example of the Hough transform plane in the experiment. The horizontal line indicates the best u position. In this case, the peak position is a little ambiguous. In addition, it was indicated that this right edge segment is originated from the rightmost of multiple pipes lying close together in parallel, because the corresponding left edge segment gave no peak on the Hough transform plane (not shown in the figure). For comparision, an example from another experiment is shown in Fig.4(b). The figure indicates that the left and the right edge segments have a common peak on the Hough transform plane. In this case(Fig.4(b)), a single pipe generated a well-defined hyperbola.

6. Aperture synthesis

For noisy data or for short segments, the 1st derivatives are not so reliable and the above Hough transform gives somewhat ambiguous result(i.e., the peak is not sharp). In this case, we must determine the velocity by a more robust scheme.

Substituting $T_0\equiv t_0^2$ to Eq.(2), we have

$$T_0=-4(x_0-x_s)^2/v^2+t^2. \quad (8)$$

In this equation, x_s and t are given for each edge point. So, if v is given, we can obtain T_0 and x_0 as the focus of parabolas represented by the following equation.

$$T_h=-4(x_h-x_s)^2/v^2+t^2. \quad (9)$$

This is the second Hough transform method. It duplicates the aperture synthesis process, in which hyperbolically spread data from the radar image is collected to determine virtual object location.

In our case, the velocity is already estimated roughly, thus this Hough transform stage is performed for several values of v around the rough estimate. The value of v that gives the most focused Hough transform plane is regarded as the correct one, and t_0 and x_0 on this plane are adopted.

This stage does not use derivatives, so robustness can

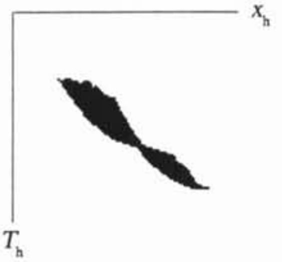


Fig.5. The Hough transform plane (II).

be expected. It is a little time consuming compared to the first Hough transform method, however, the processing time is much shorter than with the traditional aperture synthesis technique.

Figure 5 shows an example of the experimental results of the second stage Hough transform.

7. Determination of object depth

If the velocity v and the horizontal location of the object are determined, the depth of the object is given by the following equation.

$$z_0=vt_0/2=vt(x_0)/2. \qquad (10)$$

Actually, however, perfect impulses cannot be transmitted without any distortion, and because a wave train is being propagted, multiple echoes return from each single point source. In the experiment, two edge contours show the echoes from the same sources. In this case, the upper (nearer to the ground) edge segment indicates the location of the object. The estimated depths of the two outermost pipes are about 89cm and 91cm for the appropriately determined edge-detection cross level, while the correct values are 90 cm. It is said that an error rate of 10% in depth is commercially acceptable, so the proposed method gives a satisfactory result for the experimental data.

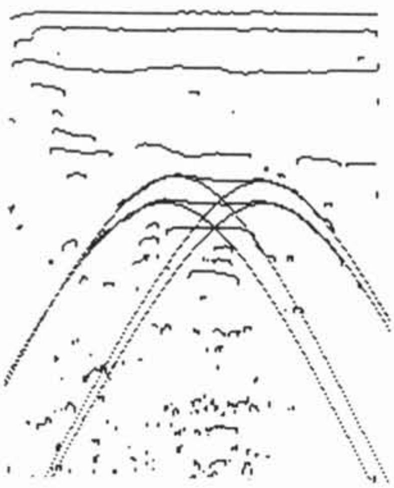


Fig.6. Superimposition of hyperbolas on the edge contours.

Figure 6 is a superimposition of the edge contours of the radar image and the hyperbolas which coincide with the velocity given by the method. It is shown that the hyperbolas well fit the significant edge segments.

It should be noted that, in many cases, we have more complicated situations. In these cases, the propagated signals consist of a weak half wave and subsequent intense half waves. The real depth should be calculated from the echo response time of the front edge of the first half wave, but this wave is too weak to form a significant edge segment and sometimes it disappears. This makes it necessary to subtract a half wave-length from the echo response time of the shallowest edge segment.

8. Conclusion

A method for locating undergound linear objects was presented. The method employs the Hough transform of a ground-probing radar image in order to estimate the velocity of microwave propagation in the ground and to know the position of pulse echo sources in the image. The method realizes high measurement accuracy with a short computation time. A preliminary experiment shows that the proposed method can give a satisfactory depth measurement from radar data containing multiple-pipe interference.

Acknowledgement

The author thanks Dr.J.Masuda and Y.Nagashima at NTT Telecommunication Service Support Headquarters for the experimental radar data and several discussions.

References

[1]N.Osumi, K.Ueno:"Microwave holographic imaging of underground objects", IEEE Trans. Antennas and Propagation, Vol.AP-33, No.2, pp.152-159, 1985.

[2]K.Deguchi, T.Okada, I.Morishita:"Analysis of underground radar image using generalized Hough transformation technique", Trans. Soc. Instrument and Control Eng., Vol.25, No.7, pp.72-79, 1989(in Japanese).

[3]T.Kaneko:"Underground structure locating using the Hough transform of a holographic pulse radar image", 2nd International Symposium on Signal Processing and its Applications, pp.597-600, Gold Coast, Australia, August, 1990.