Echo Extraction Method for a Ground Penetrating Radar

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Abstract—The dielectric permittivity of the ground and the radius of a buried cylindric pipe can be estimated from the echo profile of a ground penetrating radar by using pattern recognition technique. In the practical detection, the echo profile of a specific cylindric pipe is usually mixed with the reflection from some nearby objects. In this research, the echo profile of a specific cylindric pipe is extracted from GPR image base on F-K migration method and its inverse transform. Some numerical simulations are carried out to show the validity of the proposed method.

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1. INTRODUCTION

The ground penetrating radar (GPR) has been studied and developed to detected the buried objects such as water and gas pipes, electric cables, historic ruins and so on. Different from the conventional radar, the targets of GPR are buried in an inhomogenous lossy medium, and a GPR is expected to be able to estimate sharps of the targets as well as their locations. The efforts have been made to improve the resolution of GPR system by developing wideband antennas and imaging algorithms.

The estimation of the dielectric constant of the ground is another hard problem in GPR. Some attempts have been made to estimate the dielectric constant and the radius of a cylindric pipe from the echo profile of GPR by using pattern recognition technique [1]. It is noted that the precision of the estimation is very sensitive to the quality of the echo profile. In the practical detections, the echo profile of a specific cylindric pipe is mixed with the reflections from some nearby objects. In this research, the echo profile of a specific cylindric pipe is extracted base on F-K migration method [2] and its inverse transform.

2. THEORY

Figure 1 is the geometry of a GPR. $u(x, y, t)$ is the scattering electromagnetic wave by buried objects, whereas $u(x, 0, t)$ means the scattering electromagnetic wave on the ground surface. $u(x, 0, t)$ can be measured with a receiving antenna moving along the ground surface. An ideal 2D echo image $u(x, 0, t)$ from a single cylindric pipe is a hyperbola like curve, however, because it widely spreads in a practical 2D echo image of a GPR, the echo profile usually is mixed with the reflections of other nearby buried objects. In order to separate the scattering wave of individual buried

![Figure 1: The geometry of the problem.](image-url)
objects, a 2D spatial distribution of the scattering electromagnetic wave $u(x, y, t)$ is firstly deduced from $u(x, 0, t)$, then, it is migrated to the initial state. A concentrated distribution of the scattering wave is available with this F-K migration method. For convenience of the explanation of the inverse F-K migration transform, a brief principle of F-K migration is shown hereafter.

It is well known that the scattering electromagnetic wave must be satisfied the following wave equation,

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} - \frac{1}{v^2} \frac{\partial^2 u}{\partial t^2} = 0$$  \hspace{1cm} (1)

where, $v$ is the light velocity in the ground. A 2D Fourier transform of above equation with respect to $x$ and $t$ gives a following result,

$$\frac{\partial^2 U(\xi, y, \omega)}{\partial y^2} + \left(\frac{\omega^2}{v^2} - \xi^2\right) U(\xi, y, \omega) = 0$$  \hspace{1cm} (2)

where, $U(\xi, y, \omega)$ is a 2D Fourier transform of scattering electromagnetic wave $u(x, y, t)$ with respect to $x$ and $t$. Above differential equation is a standard second-order homogeneous differential equation and its solution is given as follows,

$$U(\xi, y, \omega) = \exp\left(jy\sqrt{\frac{\omega^2}{v^2} - \xi^2}\right) U(\xi, 0, \omega)$$  \hspace{1cm} (3)

where, $U(\xi, 0, \omega) = U(x, y, \omega)|_{y=0}$ can be obtained by Fourier transform of the scattering wave $u(x, 0, t)$ that is measured on the ground surface. An initial state of the scattering wave is given by an inverse Fourier transform of above equation. The result is shown as fellows,

$$u(x, y, 0) = \frac{1}{(2\pi)^2} \int \int \exp\left(jy\sqrt{\frac{\omega^2}{v^2} - \xi^2}\right) U(\xi, 0, \omega) \exp(j\xi x) d\xi d\omega$$  \hspace{1cm} (4)

If a short pulse is used as a transmitting signal, 2D image $u(x, y, 0)$ represents the reflection area on the buried object. Because the velocity of light is unknown, a roughly estimated velocity is usually substituted in the F-K migration computation.

In a practical migration computation, a variable transform is substituted into above equation, and fast Fourier transform is performed in order to reduce processing time as follows,

$$\eta = \sqrt{\frac{\omega^2}{v^2} - \xi^2}$$  \hspace{1cm} (5)

$$u(x, y, 0) = \frac{1}{(2\pi)^2} \int \int \frac{1}{\sqrt{1 + \frac{\xi^2}{\eta^2}}} U(\xi, 0, \eta\sqrt{1 + \frac{\xi^2}{\eta^2}}) \exp(j(\xi x + \eta y)) d\xi d\eta$$  \hspace{1cm} (6)

With above imaging processing, the scattering wave from the individual buried object are well separated in spatial domain. The scattering wave of a specific buried object can be extracted easily by an appropriately designed spatial window function as shown in Equation 7. In this research, a circular Hanning window is utilized.

$$u'(x, y, 0) = u(x, y, 0) w\left(\sqrt{(x-x_0)^2 + (y-y_0)^2}\right), \hspace{1cm} w(r) = \begin{cases} 1/2 & 0 \leq r \leq r_0 \\ 0 & r > r_0 \end{cases}$$  \hspace{1cm} (7)

where, $u'(x, y, 0)$ is extracted scattering wave, $(x_0, y_0)$ and $r_0$ are the center coordinate and the radius of the window function, respectively.

The reconstruction of a extracted echo profile is an inverse process of F-K migration. Taking an inverse Fourier transform of Equation 6, following results is available,

$$U'(\xi, 0, \omega) = \frac{1}{\sqrt{1 - \frac{\xi^2\omega^2}{v^2}}} U'(\xi, \sqrt{\frac{\omega^2}{v^2} - \xi^2})$$  \hspace{1cm} (8)
where,

\[ \tilde{u}'(\xi, \eta) = \int\!\int u'(x, y, 0) \exp(-j(\xi x + \eta y)) \, dx \, dy \]  

(9)

The extracted echo profile \( u'(x, 0, t) \) is a Fourier transform of \( U'(\xi, 0, \omega) \) that is given by Equation 8.

3. NUMERICAL SIMULATIONS

Figure 2 shows the model of numerical simulation. Three cylindric metal pipes are buried in the ground with depths of 0.8 m, 1.0 m and 1.2 m, and their diameter are 10 cm, 20 cm and 10 cm, respectively. The interval of neighboring pipes is 50 cm. Fig. 3 is the image of buried objects computed by F-K migration method. Fig. 4 is an example of the extraction of a specific buried object. Figs. 5(a)–(c) show the results of reconstructed profiles of three buried pipes. Fig. 5(d) shows the original radar echo profile.

![Figure 2: Model of simulation.](image1)

![Figure 3: Image of F-K migration.](image2)

![Figure 4: Extracted Image.](image3)

![Figure 5: Echo profile of buried objects.](image4)

4. CONCLUSIONS

The extraction of GPR echo for a specific target is proposed based F-K migration method and its inverse transform. Some numerical experiments are carried out to show the validity of the method. The estimation of the permittivity and the radius of buried cylindric pipe from the extracted echo profile will be verified in the future works.

REFERENCES