Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 15 (2011) 1393 – 1399
Procedia Engineering
www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

Research on the Algorithm of Extracting Weak Signals from Radar Images under the Double-layer Rebars Shielding

YANG Feng*, QIN Xiaoping, WEI Pengxu

School of Mechanical Electronic and Information Engineering, China University of Mining and Technology (Beijing), China, 100083

Abstract

Basement floor is a component of building structure, which is mainly made of reinforced concrete. The defects threaten the safety of building structures and the use of underground buildings all the time. The main defects in the process of construction are that the pouring thickness of floor can't reach the design demand or the loose of the base. The thickness of the basement floor, which is made of a double-layer rebars structure and often detected by high frequency radar antennae, is usually 0.4 meters. Steel mesh is highly reflective to radar waves, and is shielded from reflection information of the bottom interface of floor, so that it is too hard to reach the goal of interpreting anomalies of images using conventional approaches. Studies have shown that the modern spectrum has a higher resolution than classical spectrum, so that the algorithm of the expectation value of the modern spectrum. Which constructs profile images of radar modern spectrum by short time-window, has been presented. The spectrum profiles made characters of weak shielded signals prominent, proved the algorithm of modern spectrum profiles, by means of procession, interpretation and application of the double-layer rebar reinforced concrete structure and defects, and also demonstrated the effectiveness of the technology of modern spectrum profiles.

Selection and/or peer-review under responsibility of [CEIS 2011]
Keywords: reinforcing steel bar shielding; GPR image interpretation; weak signals analysis

1. Introduction

Basement floor is an importation part of building structures. Floor defects, such as that the thickness can't reach the design demand, or the loose base caused by damages etc, are the main reasons for cracks and water seepages, which influence not only the safety of building structures, but also the using function and its service life[1-3]. GPR is a common technology for detecting concrete structures and their defects. Different frequencies antennae are selected according to different thickness. So the smaller the thickness is, the higher the frequency of the antenna should be chosen, in order to meet the requirement of detection

* Corresponding author. Tel.:+8613501185277
E-mail address: Corresponding author. Tel.:

doi:10.1016/j.proeng.2011.08.258

accuracy. Theoretical research shows that when the thickness is less than half of the wavelength, the thickness of media can be distinguished better from radar profiles[4]. When the detection depth is bigger than 0.9 meters, using the antenna of 400MHz frequency could obtain better results. However, after the floor has been reinforced with double-layer rebars, there is no good solution to extract information of week reflection and defects in images of floors' bottom interfaces under strong disturbances of rebars. By research, this article presents a technology of constructing profile images of radar modern spectrum, to reach the goal of abstracting weak signals from strong shielded radar images.

Taking detection of basement floors' structures and defects in a certain residential area in Fuzhou as example, the study on radar scans has been carried out. The basement floors are made of double-layer rebars structures. The rebars cause heavy influences on electromagnetic wave reflection and diffraction from radar wave signals, and shield the response signals from every surface and defect of basement floors. Especially, effects of double-layer rebars shielding are greater. Therefore, it is too difficult to obtain abnormal information of interfaces and defects directly from regular GPR time profile images. The indirect interpretation method, which uses the differences of spectrum response features between different media to explain, can be used. Spectrum analysis methods are classified into two categories: the non-parameterization methods and parameterization methods. The non-parameterization spectrum analysis, for example, the periodogram method, so called the classical spectrum analysis, whose main defect is low in frequency resolution; while parameterization spectrum analysis also called the classical spectrum analysis, whose advantage is that its frequency resolution is high[5,6]. This article firstly did some research on differences of frequency response features between modern spectrum and classical spectrum with comparison. And the results proved that the modern spectrum is more obvious to highlight frequency response parameters. Based on the research, a method to compute the expectation value of the modern spectrum has been presented. Then the construction profile images of radar modern spectrum on the basis of the expectation value of the modern spectrum, by way of short time-window sliding smoothly, it finally achieved the aim of interpretation of different spectrum profiles among different space media.

2. Analysis response characters of traditional and modern spectrums

Figure 1 shows the design model of basement floor. The thickness of concrete floor is designed to be 0.4 meters. And the floor cushion is set to be 0.5 meters. The floor is made of double-layer rebars, and the diameter of one rebar is 0.01 m, and the space between the rebars is 0.18 m.

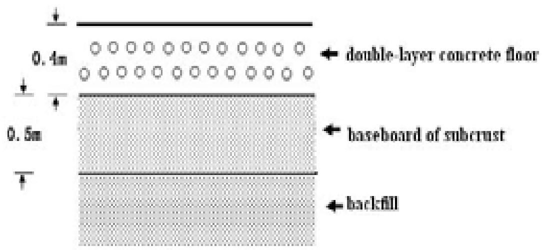

Fig. 1 The floor model of basement

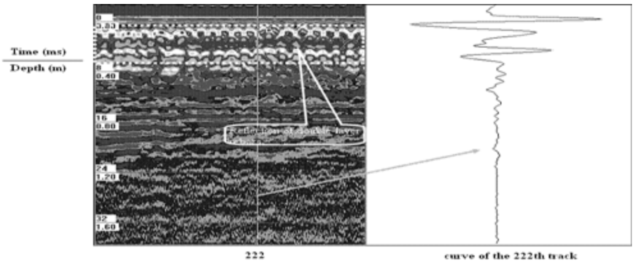

Fig. 2 The section and curve of basement floor

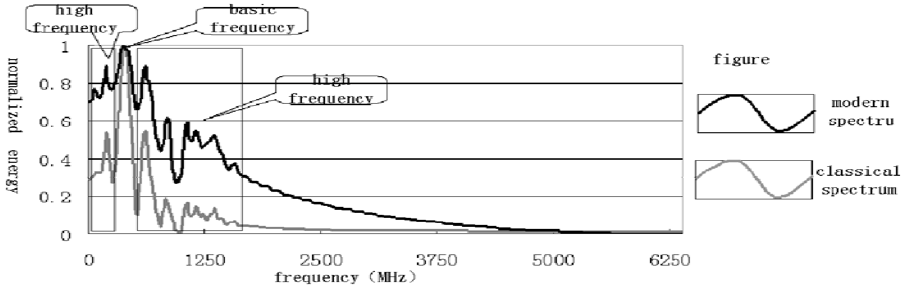

Fig. 3 The contrast for spectrum of classic to modern spectral

Figure 2 shows the radar profile of basement floor detection using 400MHz antenna, and the radar reflection curve of the 222th track. The double-layer rebar reflection character is easy to be discovered from the radar profile.

Figure 3 shows the contrast result of classical spectrum and the transform of modern spectrum on the 222th curve in the radar profile. The classical spectrum indicates that the radar curves' energy have great differences based on different frequencies. The dominant frequency of the signal is 375MHz. With the increase of the frequency, the attenuation of signal energy is quite fast, which proves the classical spectrum has poorer ability for resolving weak signals. On the contrary, the modern spectrum has higher ability for resolving the same weak frequency signals. That means, with the increase of the frequency, the attenuation of the spectrum value is relatively slow.

For the radar detection data, the above parts have described that the modern spectrum has a higher ability of resolving than classical spectrum. However, how to extract modern spectrum characters of reflection information in different media in order to reach the aim of distinguishing surfaces and deflects has been proposed. Hence, this article presents a way of short time-window sliding and the algorithm of the expectation value of the modern spectrum to extract continuous spectrum characters of signals. Thus profiles of different time depth based on modern spectrum characters have been constructed.

3. Construction algorithm of modern spectrum sections

3.1. Calculation of modern spectrum

This article adopts the ARMA modern spectrum molding method, which is used to build models by the process of smooth linear signals to estimate spectrum density.

Set $\{x(n)\}$ as radar digital signals, if they satisfy difference equation:

$$x(n)+a_1x(n-1)+\cdots+a_px(n-p)=e(n)+b_1e(n-1)+\cdots+b_qe(n-q) \quad (1)$$

the process of $\{x(\mathrm{n})\}$ is called ONE ARMA (p,q) process. $e(\mathrm{n})$ is the white noise whose average value is zero and whose variance is c^{2}, which is $\{e(\mathrm{n})\} \sim WN(0,\sigma^2)$ in short; a_{i} and b_{i} in the equation are called autoregressive (AR) parameter and moving average parameter respectively; p and q are called AR and MR. Geological acquisition signal reflects the changes of underground permittivities in different depth. The change is unknown and it can be simulated by the white noise.

Using formula (1), the spectrum density parameters of the $\{x(n)\}$ signals can be calculated

$$P_x(\omega) = \frac{|B(z)|^2}{|A(z)|^2}\sigma^2 \tag{2}$$

In this formula, $z = e^{-j\omega}$, $A(z) = 1 + a_1 z^{-1} + \cdots + a_p z^{-p}$, and $B(z) = 1 + b_1 z^{-1} + \cdots + b_q z^{-q}$. The method of Cadzow spectral analysis can be used to achieve the calculation of modern ARMA spectrum

3.2. Calculation of the expectation value

Formula (2) can be used for calculating modern spectrum characters in the whole detection depth range. Because it can't reflect the unknown information in local depth range, so extracting local modern spectrum parameters by adding time window is needed.

(1) Time window selection

The modern spectrum density of corresponding time depth points can be obtained by adding the number of time window.

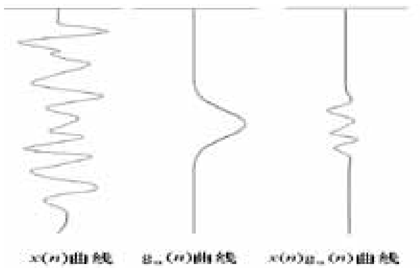

Fig. 4 Sketch map of the curve and results of add window

The rectangular function, gable function, spline function of degree m interpolating and etc can be used as the time window function. To select the window function must be based on the uncertainty principle. The uncertainty principle states that the area of window function $g(t)$'s satisfies

$$4\Delta_{g(t)}\Delta_{\hat{G}(\omega)} \geq 2 \tag{3}$$

If and only if $g(t)$ is Gaussian function, which is $\mathrm{g}_\alpha(n) = \frac{1}{2\sqrt{\alpha\pi}} e^{-\frac{\mathrm{n}^2}{4\alpha}}$, $4\Delta_{g(t)}\Delta_{\hat{G}(\omega)} = 2$. And the Gaussian window is the best one for local analysis. So this algorithm chooses the Gaussian window as window function.

(2) Construction of the expectation value of spectrum density

The radar signal in $\{\mathrm{y}(n)\}$ can be obtained by load signals from short time window, $\{x(n)\mathrm{g}_\alpha(n)\}$, as figure 4 shows. After being window loaded, the curve describes mainly the signal changes in the window. Using formula (2) and $\{\mathrm{y}(n)\}$, the curve of modern spectrum characters of internal signals in the window can be calculated.

Assume that $x(t)$ is the information of a certain track in the radar time profiles, that t_0 is a randomly selected time depth in the time profiles, ΔT is the window length, short-time window modern spectrum of short time signal $x(t)g(t - t_0)$ .Its starting point is t_0. And the window length is ΔT. The calculation results of the modern spectrum reflects the characters of spectrum from $[t_0 - \Delta T/2]$ to $[t_0 - \Delta T/2]$. Using Δt as time interval and the discrete signals, which using N as its sampling points, the results of the spectral transformation is discrete spectrum which uses $\Delta\omega = \frac{1}{2\pi\Delta t \times \mathrm{N}}$ for intervals. Therefore, the calculation results by using formula (2) are a modern discrete sequence. It is difficult to contrast the modern spectral information of GPR wave responses while using the discrete sequences to present the moment t_0. How to transform the discrete sequence into a value, then use it to express the modern spectrum parameters of time depth point is very important. Because the responses of layers at different depth to the antenna of certain frequency are unpredictable, the expectation parameters of modern discrete spectrum, citing from the conception of mathematical expectation in random process have been used. The following formula is the concrete realization:

$$Q(t_0) = \frac{1}{N}\sum_{n=0}^{N}\left|\mathrm{P}_x(n\Delta\omega)\right| * n\Delta\omega \tag{4}$$

Formulation (4) mainly reflects the expectation value of modern spectrum density in the short time window from $[t_0 - \Delta T/2]$ to $[t_0 + \Delta T/2]$.

If the size of time window is ΔT, and the window scrolls down along the time from the beginning, every points of time depth corresponds to the spectrum expectation value in the formula (4). Then the rolling modern spectrum profiles can be obtained.

Because the GPR obtains real signals whose values are symmetric, so the part of the frequency which is on the positive semi-axis can be chosen for analysis. The starting time is regard as the reflection time of radar profiles. Therefore, there is mapping relationship as the following in every GPR track：

$$x(t_0) \quad = \quad Q(t_0) \tag{5}$$

Where t_0: 0, Δt, 2Δt, … , (N - 1) Δt ; $x(t_0)$: Information at the t_0 depth time point; $Q(t_0)$: Expectation value of spectrum density of short-time window from $[t_0 - \Delta T/2]$ to $[t_0 + \Delta T/2]$; Δt : Time interval of sampling points; N : Total number of sampling points.

4. Application Analysis

Aiming at the quality test of the coagulation bolt floor of a basement in a populated area in Fuzhou, the Figure 5 shows the GPR time profile for basement slabs. Because of the strong diffraction caused by double-layer rebars structures, all the information of lower interface and defect has been shielded. Therefore, it is not possible to get the depth and defect information of basement slabs. By the traditional direct interpretation method, it is very hard to get the detection results.

Figure 6 shows the modern spectrum GPR profile from the short time calculation. From the above analysis, the short time window in different smoothed moving processing of different interfaces contains two kinds of response information of modern spectrum in two different media. Therefore, in this kind of time window, the signal band is wider. According to the formula 4, a higher expected value of modern spectrum can be figured out, the concrete bottom boundary and the baseboard of subcrust. When the signal of GPR transmits in the disorder backfill media, because of the nonuniform media and oversize interspace, the interference and scattering overlies. Thus, it enhances the response band of signals and also has a higher expected modern spectrum value. Figure 6 shows the defect area of GPR. Therefore, by calculating the time profiles and spectrum profiles of GPR, by different response attributes of modern spectrum, the weak signal sharp interface and defect information can be picked up from the strong reflex signal interference.

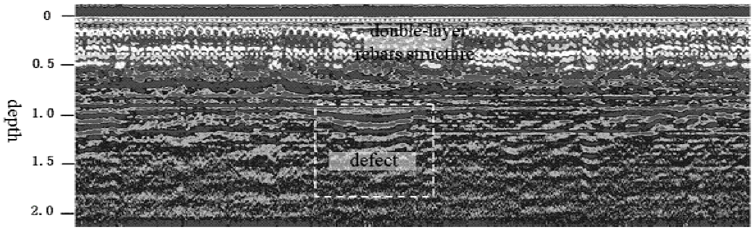

Fig. 5 The GPR section for detection

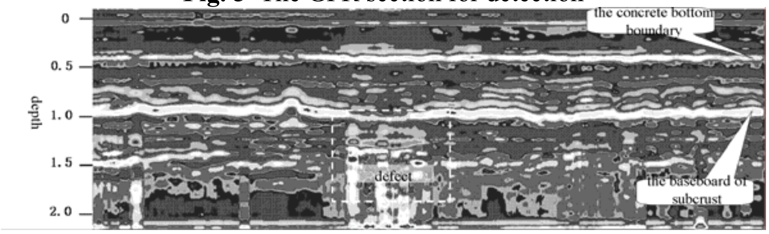

Fig. 6 The modern Spectral section

5. Conclusion

GPR has been widely used in the field of structure detection of concrete constructions, such as depth of tunnel lining, highway surface thickness, etc. But if the double rebar structures have been used for reinforcement, because of the reflection and diffraction, information of lower interface has been shielded and caused the bottleneck of GPR method in construction detection. This article put forwards the following ideas:

(1) Comparing with classical spectrum, the modern spectrum has higher resolution in GPR response signals.

(2) This article presents the concept of modern spectrum and its computing methods. By describing the profile of spectrum, the response information of defect weak signals and strong interference bottom boundary for the detection purpose.

Support: Supported projects: Program for New Century Excellent Talents in University of Ministry of Education of China (NCET-08-0834); Special Fund for Basic Research on Scientific Instruments of the National Natural Science Foundation of China (50927805); National Key Technology Research and Development Program of the Ministry of Science and Technology of China (2011BAD04B05).

References

[1] YU Lirong, MO Shihai, WANG Lunbing. Basement Foundation Slab Cracking Analysis and Disposal in a Project[J]. Construction Quality, 2009, 27(3):53-54

[2] HU Guicang. Technical Measures for Construction of Later-Poured Belt in Basement Foundation[J]. Architecture Technology, 2007, 38(11):824-825

[3] LI Wei, QIU Shenghua. Analysis on Soll Reaction Bearing Proportion for Basement Slat Design[J]. 2009, 40(6):539-541

[4] YANG Feng, Peng Suping, Liu Jie. Simulation of Void Area in Cement Concrete Pavement Base on Radar Wave and Explanatory Strategy[J]. Journal of the China Railway Society, 2008, 30(5):92-96

[5] YANG Feng, Peng Suping. Research on Ground Penetrating Radar (GPR) Exploration on Subgrade Failure Based on Spectrum Profile[J]. Journal of Highway and Transportation Research and Development, 2007, 24(5) : 6-9

[6] YANG Feng, Peng Suping, Zhai Bo, HAO Lisheng. Research on Ground Penetrating Radar (GPR)

Exploration on Void under Approach Slab[J]. Journal of Highway and Transportation Research and Development, 2009, 26(4): 37-41
[7] ZHANG Xianda. The Modern Signal Processing[M]. Beijing: Tsinghua University Publishing Company,1999
[8] HU Guangshu. The Modern Signal Processing Tutorial[M]. Beijing: Tsinghua University Publishing Company, 2004
[9] YANG Feng, SU Hong-qi. Geological radar technology and application in highway tunnel detection[J]. Road Machinery & Construction Mechanization, 2005, 22(10):8-10.
[10] LI Jin-ping, SHAO Pi-yan, GU Mu. Application and Analysis of GPR in Railway Tunnel Engineering Quality Inspection[J]. China Railway Science, 2006, 27(2):56-59.