A complete analysis of focusing the GPR data on rebar mesh obtained within cement based structures using Simulation Migration Algorithms

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Abstract— Ground Penetrating Radar (GPR) is a technique based on propagation and reflection of electromagnetic waves in the subsurface .The B-scan of the GPR images on the concrete structures produces scatters, which generally exhibit defocused, hyperbolic arc characteristics.This is mainly due to the data collection scheme, which produces the effect of clutters along with the scatters that are picked up by the B-scan and the finite beam width of the main lobe of the GPR antenna. To invert this undesirable effect and obtain focused images, various focusing migration algorithms has been developed which is applied to the B-scan images to enhance the resolution quality of the image.This paper describes the experimental determination of GPR data taken using a 2.6 GHz antenna frequency. In this paper, the performance and the practical usage of migration or focusing velocity simulation algorithms namely frequency wavenumber (F-K) is tested and examined on the collected GPR data.The data were collected in laboratory condition of a rebar mesh in concrete structure and in air medium..

Index Terms— Ground Penetrating Radar (GPR), frequency wavenumber migration algorithm, Electromagnetic waves.

1 Introduction

GRound Penetrating Radar (GPR) is a technique based on propagation and reflection of electromagnetic waves through a wideband antenna into the subsurface. Many other techniques include visual solutions via manholes and gratings, and also a range of non-visual solutions including metal detectors, acoustic and seismic methods, magnetic surveying,electrical-resistivity methods, gravity-surveying, thermographic and electromagnetic methods.Whilst other methods may have their unique advantages and disadvantages, a great importance is given to the GPR because of the ability to detect metallic and low-metallic objects like pipes,rebar , cables on concrete structures by non-invasive subsurface sensing[1].Still, its main drawback is the complex nature of its data and then their interpretation is usually limited in defining general “areas of interest” instead of accurately determining the shape and position of the target.The B-scan taken from the GPR during measurement is the scattered data that is recorded from a number of spatial positions on a straight scan by moving the antenna over the concrete sample surface. The recorded data along the surface is a 2D space–time GPR image. The B-scans shows undesired low resolution hyperbolic arc shaped signals. However, in many real applications, the heterogeneities of the media can be important and it becomes necessary to use an algorithm that takes into account the spatial changes of velocity in the media. Various focusing or migrating algorithms have been developed to solve this problem of getting GPR images with high spatial resolution. For a specific GPR application depending on type of antenna, homogeneity of the medium, frequency etc, the appropriate migration algorithm should be used. In this paper, the frequency wavenumber (F-K) migration is applied to the collected data and the results are discussed. The data are also verified with the laboratory experimental gpr data taken from metal grid in the form of mesh within the concrete samples and in air medium.

2 GPR Equipments

The commercial GPR instrument SIR-2600 (GSSI) used in this study consists of data acquisition equipment and radar treatment equipment. The equipment used for data acquisition consists of a central unit (a computer with the radar data acquisition software) and ground coupled antennas as shown in fig 1. The data treatment equipment is usually a computer and appropriate software to visualize, filter and interpret radar data. These antennas are connected to the main unit with a coaxial cable and they are usually bowtie antennas designed to generate and detect electromagnetic pulses.

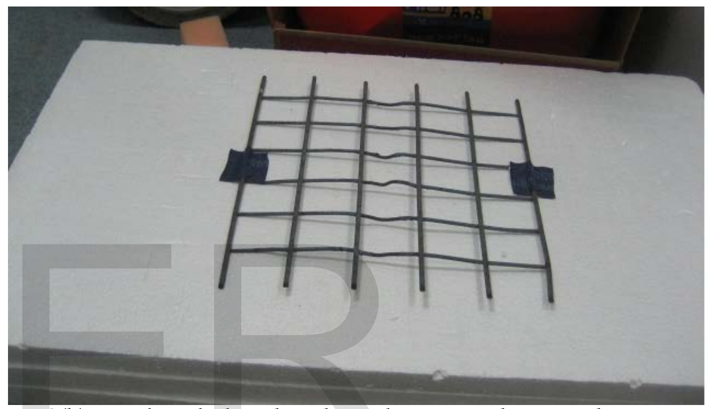
Fig 1 GPR and central unit with 2.6GHz center frequency antenna

They are prepared to work in direct contact with the surface of the structure under study [2 and 3].The radiated frequencies of these antennas depend on their configuration and on the dielectric properties of the materials to which the near field of the antenna is placed in contact. Antennas are named using the centre frequency of the emitted waveOne of the special apparatus of field acquisition used is 2.6GHz antenna, seems to be enabled to provide good topographic and three-dimensional restitution with regard to location and placement compared to other low frequency acquisition systems used so far in the past researches. These data-sets are collected both as 2D and 3D data-sets (B-scans). The system of data acquisition was carried out in profiles covering different sections of the rebar mesh embedded in concrete sample and in air as medium.A total of 25 profiles was studied.

3 EXPERIMENTAL MEASUREMENT SETUP

The data were acquired from concrete structures as in fig 2(a) which were sample blocks from airfield runway and metal grid rebars placed as rebar mesh placed over polystyrene sheets with air as medium as shown in fig2(b).

Fig 2(a) Concrete airfield runway sample.



2(b) metal grid placed under polystyrene sheets with air as dielectric medium

In general, the dielectric constants are different according to surface layer, base layer, air, void, water void and crack. The study was focused on the signatures of scan data obtained in two dimension (2D). For the acquisition, a monostatic radar system in the time-domain with a 2.6GHz developed by the GSSI Group was used. All data had been recorded using a 5 ns time window of 512 samples per trace corresponding to a time sampling interval of approximately 0.00978ns.The antenna system was positioned above the concrete surface and the data have been acquired along one surface direction [4]. The distance was measured by an incremental encoder connected to the system.The antenna was moved with constant speed. In the case of the airfield runway samples the first layers of rebar were located at a depth of 2 cm. In the case of the metal grid the grid was plaes 4 cm below the polystyrene sheets.The GPR raw data was taken at a frequency of 2.6 GHz with the GPR unit, which was moved over the concrete traces. Reflected GPR data from the continuously moving antenna was recorded as a series of hyperbolic arc (traces), with each trace consisting of the summation of many reflections from the reinforcing steel bar.

To test the focusing algorithms, B-scan data were collected over the runway sample and laboratory metal grid set up. During the experiments, the antenna was moved very close to

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the surface. The raw data image of the concrete runway sample recorded from the GPR display shown in figures 3(a) and 3(b) are that of the metal grid placed in air. This is an unfocused space depth raw GPR images of the rebar collected .Due to the well homogeneity of the medium the rebar are well distinguished in the image [5]. The reflections from the air concrete interface are highly suppressed and most of the energy penetrates into the concrete structures [6]. Hence scattering from the bottom of the sample are also seen.

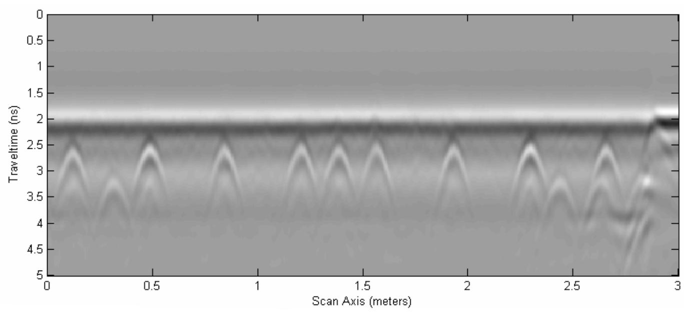


Fig 3(a) Raw data image of a concreteAirfield runway sample

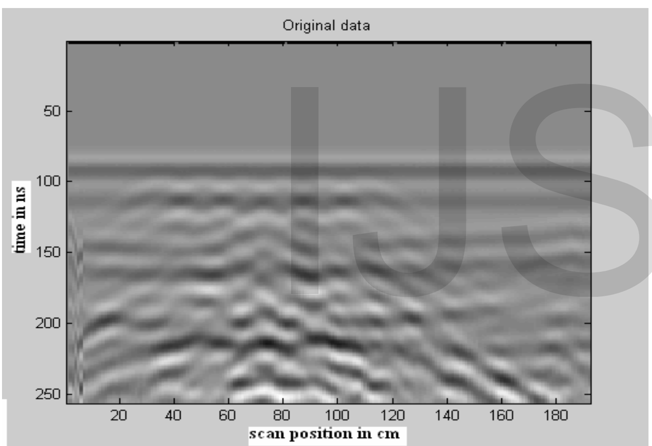


Fig 3(b) Raw data image of the metal grid placed in air medium

4 GPR FOCUSING ALGORITHMS

4.1 Frequency wavenumber (F-K) focusing migration

Imaging techniques can be used to focus the energy present in a target's hyperbolic arc to a single point. The present F-K migration technique [7] used is based on a scalar wave equation and is an efficient spectral technique. The derivation of F-K migration is based on a transformation from the frequency domain w to the wavenumber domain k (the Fourier transform of space or distance). Considering over the raw data set b(x, z, t) collected from the radar source distribution in a homogenous medium with propagation velocity v, the B-scan distance x, the depth z, and the time-of-flight t, a 2D Fourier transform with respect to the spatial distance x and the time t to spatial frequency kx, derived is an unfocused wavenumber data set as (1)

$$B(k_x, z, \omega) = \int\int b(x, z, t) e^{ik_x x - i\omega t} dxdt \qquad (1)$$

The Fourier transformation along the x coordinate only makes sense, if the propagation velocity does not vary in this direction. The method allows variations of the propagation velocity in the z direction. Defining the wavenumber vector k as the vector sum of kx and kz for one-way propagation, it is written as (2)

$$k = |k| = \sqrt{k_x^2 + k_z^2} = \frac{\omega}{v} = \frac{2\pi}{\lambda} \qquad (2)$$

in which v is the propagation velocity of the ground (v =c/√εr), εr is the relative dielectric permittivity extracted from the equation of the hyperbola) and l is the wavelength in the sample.The direction of the k-vector is identical to the traveling direction of a plane wave propagating from target to the antenna. Assuming only upward coming waves and by introducing kz from (2) in (1), the Fourier transform of the wavefront at depth z is given as (3)

$$B(k_x, z, w) = B(k_x, 0, \omega) e^{-ik_z z} \qquad (3)$$

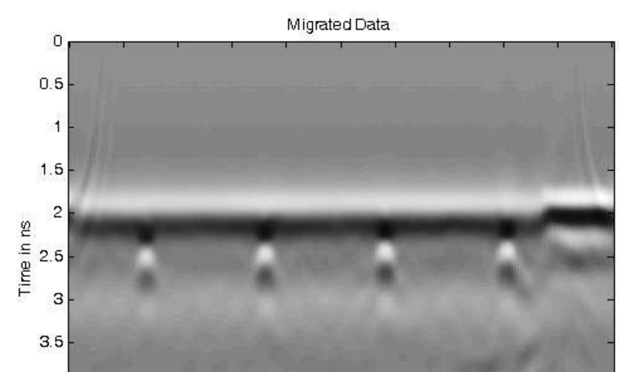
The migrated data will be the inverse Fourier transform of (3) at time t=0.

$$b(x, z, 0) = \iint B(k_x, 0, \omega) e^{-i(k_x x + k_z z)} dk_x d\omega \qquad (4)$$

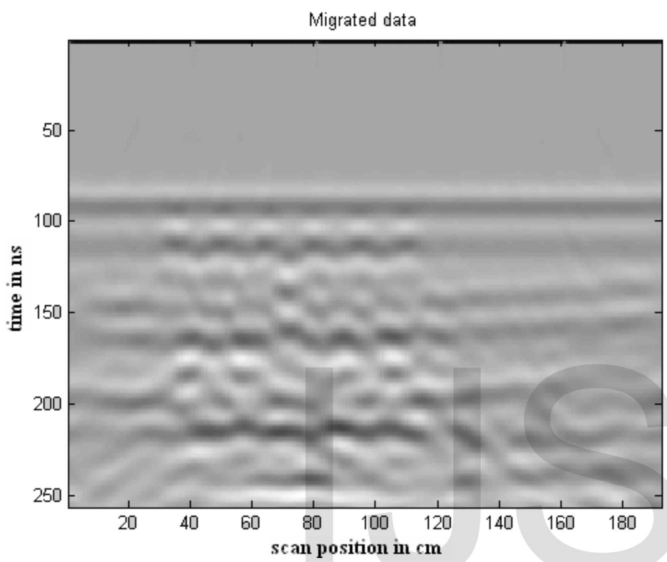
Equation (4) is the general representation of the F-K migration. Here b (x, z, o) is the focused GPR image in the spatial domain after the migration.

5 SIMULATED RESULTS OF THE FOCUSING ALGORITHM

The focusing algorithms were tested, by running it on with the data collected from the concrete block and the runway samples. The simulated images using F-K migration are given in figures 4(a) and 4(b).



4(a) F-K migrated images of runway sample



4(b) F-K migrated images of the Metal grid sample in air

6 CONCLUSION

In this paper, F-K migration algorithm has been applied on real GPR data. The GPR data collected from the interactive runway sample allow to analyze the reflections of a buried reinforced steel bar in concrete. The Matlab codes written to simulate migration algorithms on the GPR data make the process of preprocessing more precise and encouraging. When comparing Fig 3(b) and 4(b) it can be seeen that the 6 six vertical vars in the mesh are clearly seen in the migrated images. The size of the object can be deduced from the migrated data. These algorithms are not computationally intensive. However, the simulated results from the algorithm used are compared and verified with the experimental data obtained from the concrete samples under study.

7. References

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