Review of GPR Rebar Detection

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Abstract— The background and current state of the art of ground penetrating radar testing of rebar in concrete is briefly reviewed. This encompasses developments of Polarization in rebar detection, diameter detection, corrosion detection,neural network and other automatic method in rebar detection.

1. INTRODUCTION

Radar uses an electromagnetic signal and was first applied by Huelsmeyer to detect metal objects in 1904 [1]. Applications of GPR to Structures started to grow in the 1980s [2]. Initial civil engineering applications included condition assessment of highway pavements and their foundations, with applications to structural concrete focusing on inspection of bridge decks. Cantor [3] reviewed early developments in these areas in 1984, and Clemena reviewed radar testing of concrete in 1991 [4]. Bungey [5] reviewed the recent development in equipment, materials characteristics, signal processing, numerical modeling and practical aspects of applications and interpretation in concrete survey, authorities guidance was published In the UK and in USA for the test of concrete [5–8].

Principle current and potential applications are summarized below:

Estimation of element thickness from one surface.
Location of reinforcing bars and metallic ducts, and estimation of the concrete cover depth.
Determination of major construction features.
Location of moisture variations.
Location of voids.
Localization and the dimensions of voids.
Estimation of bar size [5, 9–15].

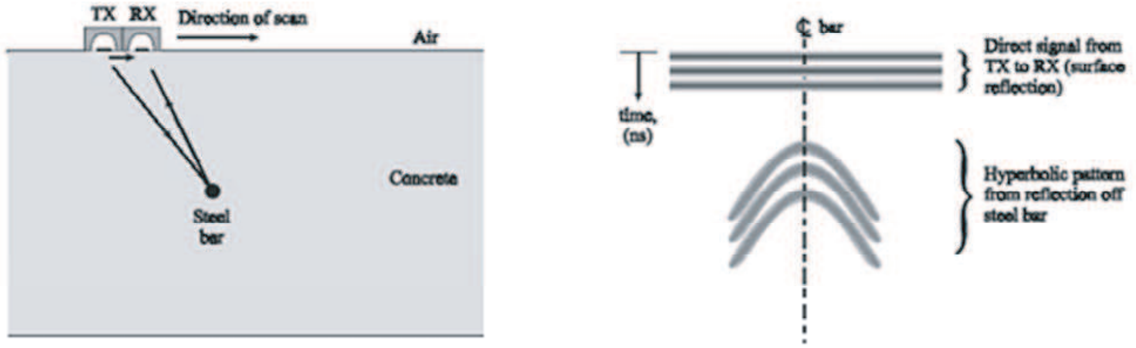
Amongst these, location of reinforcing bars is an important and popular application that has received particular attention with emphasis on the effects of bar size, spacing and depth upon ability to detect individual bars and the problems caused by masking of deeper features [5–16].

In 1997, Concrete Society published the standard specification for the radar methodology [17], while in 2003 the Federation of Construction Material Industries of Japan proposed two drafts test standard (Method for locating of rebars in reinforced concrete by radar and Method for locating of rebars and determining the diameters of rebars in reinforced concrete by electromagnetic induction) [18].

Ground-penetrating-radar is an electromagnetic investigation method. Mostly it is used in reflection mode where a signal is emitted via an antenna into the structure under investigation. The arrival time and the ampleness of reflected signals caused by changes in material properties is recorded and analyzed. The result can be present in A-scan, B-scan and C-can. In civil engineering applications it is more conventional to present these same results by converting the magnitude of the signal into a grey-scale or color representation (B-scan) [5]. The vertical axis is a time axis. In order to obtain depths the signal velocities in the different materials under investigation have to be known and the time interval (wave propagation time), can be transformed to a space dimension (depth) [19, 20].

For the reinforcement concrete, concrete could be regarded as isotropy medium in reinforced concrete structure, but the rebar would be regarded as abnormal objects [21]. Radar wave would be shapely reflected at the interface between rebar and concrete because there exists strong abnormality between the two mediums. As a radar antenna is translated across the surface of the concrete a series of signals returning to the receiving antenna can then be presented as the raw results. Signal reflections from reinforcing bars displaying a hyperbolic image format (Figures 1 and 2).

Detection of reinforcing bars in concrete is one of the most widespread applications of GPR in Civil Engineering [20, 22, 23], but the results is very difficult to interpret and may require the skills of an experienced operator and the use of lengthy manual post-processing and subjective expertise to



(a) Sub-surface reflection (b) Singal reflection image

Figure 1: Hyperbolic reflection image from steel bar concrete.

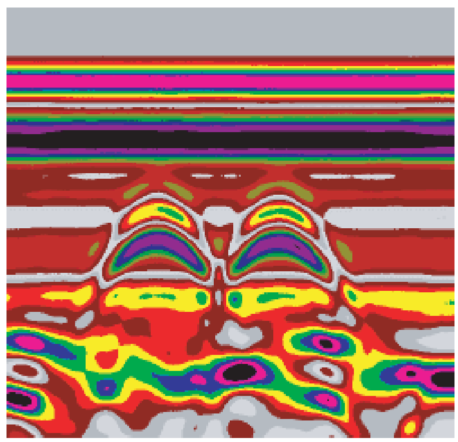


Figure 2: Radar image from sub-surface steel bars.

produce a reliable end result [10, 15]. Because the visual representation of this result can bear little resemblance to the shape or size of the sub-surface bar. Recent years many automatic algorithms have been developed for interpretation [5]. Neural networks potentially offer considerable scope for automatic interpretation of radar results [24, 25], however, success has so far been limited to straightforward cases such as reinforcing bar location. Bar sizing is more difficult and there is little evidence of industrial usage.

The potentially enhanced value of test combinations is widely recognized, for example by combining radar with infra-red thermography [26] or impact echo [27] according to the application whilst combination with both Impact Echo and radiography [28] has also been proposed.

Optimization of antenna orientation, to take advantage of signal polarization, is an important feature in successful location of reinforcing bars in time-depth slice [29].

2. POLARIZATION AND REBAR DETECTION

Polarization, the direction and amplitude of the electromagnetic field as a function of time and space, can have a significant impact on the GPR response, and is therefore important to consider during data acquisition, processing and interpretation [30–34]. Investigations have demonstrated the potential of using the polarization characteristics of GPR for defining the size, shape, orientation, and material properties of buried objects [35].

The scattering properties of rebar are strongly polarization dependent. The backscattered fields from rebar may be strongly depolarized depending on the orientation of the rebar relative to the antennas, and the radius of the rebar compared to the incident wavelength [36]. These polarization dependent scattering properties have important implications for rebar detection, survey design, and data interpretation. The radiation from rebar is linearly polarized, thus the reflections can be maximized by varying the antenna orientation [5].

Most commercial GPR antennas are dipole antennas that radiate linearly polarized energy with the majority of the radiated electric field oriented along the long axis of the dipole [37, 38]. A co-pole antenna configuration receives reflected and scattered energy that has the same polarization as the incident energy. Rebar yield strong reflections when oriented parallel to the long axis of a dipole transmit antenna in a co-pole antenna configuration, but yield weak reflections when oriented orthogonal to the transmit antenna.

A cross-pole configuration is less sensitive to smooth planer targets, and is more sensitive to targets that yield more depolarized energy [32]. It is important however to consider polarization when planning a GPR field survey, as the sensitivity of cross-pole and co-pole antenna arrangements are different depending on the type of target and subsurface conditions.

Crossed-dipole antennas can be used to reduce clutter and improve antenna isolation when stratigraphy is considered clutter and only rebar are of interest. Maximum amplitudes are observed over rebars when the crossed-dipoles are oriented at 45° to the rebars. Optimization of antenna orientation, to take advantage of signal polarization, is an important feature in successful location of reinforcing bars in the time-depth slice.

For the processing of GPR data, scalar migration algorithms developed for three-dimensional seismic data are commonly used. However, these algorithms do not account for the radiation characteristics of GPR source and receiver antennas or the vectorial nature of radar waves. A multi-component vector imaging algorithm that takes into account the polarization and vectorial radiation characteristics of GPR data has recently been developed or far-field [39, 40]. R. Streich and J. V. D. Kruk [41, 42] developed multi-component vector imaging scheme that jointly images co-polarized and cross-polarized data accounts for the far-, intermediate-, and near-field contributions to the radiation patterns. Polarization of the electric field can be used to reduced unwanted reflections [43, 44]. Polarimetric stepped-frequency GPR and fully-polarimetric processing technique have also be developed considering the polarization [45] for GPR detection.

Polarization can be used to improve S/N ratio, Co-pole and cross-pole antenna configurations can be combined with polarization dependent scattering characteristics of subsurface objects to recognize and reduce antenna ring-down for improved imaging and interpretation of rebars [46, 47], also can be used to detect the dual layer rebar mesh [48].

Detection algorithm searches a target response using neural networks and discriminates the target response of a buried pipe among clutters by analyzing the polarization characteristics. Polarization also can be used to discriminate rebar from other linear target such a dielectric cylinder [49].

3. MEASUREMENT OF REBAR DIAMETER

It is known that Ground Penetrating Radar (GPR) can be used to provide an indicative measurement of the size of reinforcement bars [50] despite it is difficult and little industrial application. Vincent Utsi [51] had used GPR to estimates of bar diameter based on the X/N amplitude ratios (the amplitudes ratios of the bar signals along and across the E-field) and the rebar sizing accuracy is about 20%. As the X/N ratio is easy to be distorted, so practical application is highly dependent on the specifies of the built environment.

M. R. Shaw developed a neural network approach [52] to automate estimation the diameter of reinforcing bars by analyzing the data taken with the transducer axis parallel and then orthogonal to the bar using a MLP neural network. It is estimated effectively, but not very accuracy and it is conditionally.

Rebar is one of the cylinder targets which is popular for GPR detection, for estimation of the diameter of rebar there also have two procedure as other cylinder such as pipe.

One is the mathematical model of the hyperbola another is hyperbola fitting.

The reflection signal present in radargram is a hyperbola as show in Figure 3, so we can establish some relation between the radius of rebar and the geometry of the hyperbola.

Stolte and Nick [53] investigate the relationship between cylinder radius and hyperbola eccentricity for the purpose of migration, while Olhoeft [54] attempts in to derive radius information from the curvature of the hyperbola apex with human intervention. Al-Nuaimy [55] et al., presented one model relates the two-way travel time t to the horizontal position x and the velocity of propagation v. But this model relies on the assumption that the hyperbolic signatures, result from point reflectors, and hence the radius is assumed to be zero. Using this model to characterize the signatures of such targets leads to erroneous information. S. Shihab and W. Al-Nuaimy [56, 57] develop a more generalized equation that takes into account the possibility of a finite radius R. This allows for cylinders of arbitrary radii to be detected and characterized uniquely from a single

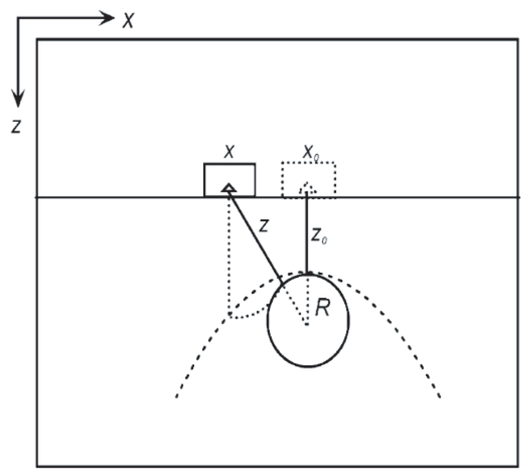


Figure 3: Effect of changing the value of R on the resulting hyperbola.

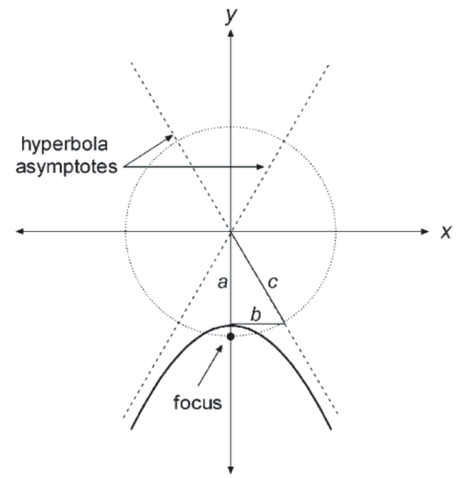


Figure 4: A general hyperbola with its asymptotes and related parameters indicated.

radargram. S. Shihab also establish the following relation between R and the general hyperbola centered around (x_0, y_0) Figure 4.

$$a = t_0 + \frac{2R}{v} \tag{1}$$

$$b = \frac{v}{2}\left(t_0 + \frac{2R}{v}\right) \tag{2}$$

The fitting of primitive models to image data is a basic task in pattern recognition,fitters specific to hyperbola is important as the hyperbolic signature is popular for GPR detection. Hough transform-based approaches develop by Al-Nuaimy [58] are simple, but are computationally expensive. Polynomial methods [5] develop by Olhoeft do not adequately characterize the hyperbola in terms of the parameters a and b, and hence fall short of providing the necessary information for target identification. S. Shihab and W. Al-Nuaimy [57] develop a fitter based on direct least-square method and was specifically adopted for a hyperbolic conic section, overcoming the above limitations. It can adequately deal with noisy data having missing points and is completely efficient. Both a, b and t_0 are obtained as a result of the fitting process and v and R can be calculate from a and b.

The fitting technique is applied on a variety of real hyperbolic signatures that are collected from a controlled test site, the results indicate this technique is fully capable of successfully estimating the depth and radius to within 10%, which validates the method and justify the assumptions used. In two-dimensional data [59] obtained from orthogonal sounding of cylinders are analyzed. It is shown that the generalized Hough method can be used to measure buried pipe diameters from radar measurements. An interactive technique of 3D-data processing is developed by B. A. Yufryakov and O. N. Linnikov [60] to estimate cylindrical objects radius directly and automatically.

A. Dolgiy and V. Zolotarev [61], considered some practical examples of pipes radius estimation on the basis of the technique presented in [56], and designated some problems appeared during this process. The pipe radius estimations in and were performed without taking into account, for example, random errors of measurement of delay time for the signal reflected from pipes [50, 52]. A. Dolgiy and V. Zolotarev [62] use the techniques based on the weighted least squares method, the recursive Kalman filter, the maximum likelihood method, the direct least-square fitting of hyperbola and the Nelder-Mead direct search method of optimization.

For a pipe with smaller radius, fast attenuation of the GPR signal was observed with distance increase between the antenna and pipe. Therefore small difference between maximum and minimum delay times of the signal reflected from pipe and also short azimuthal length of a hyperbola were acquired. As a result the error for estimation of pipe radius is increased.

4. CORROSION DETECTION

Corrosion of rebar in concrete structure causes subsurface cracks and is a major cause of structural degradation that necessitates repair or replacement. Early detection of corrosion effects can limit the location and extent of necessary repairs, while providing long-term information about the infrastructure status [63, 64].

There are many factor that induce the rebar corrosion, among the various influential factors, moisture and chloride contents of concrete are predominant in the initiation of rebar corrosion, and reversely the rebar corrosion resulting in cracking and saplling of concrete cover and allow more infiltration of water and chloride and also cause delamination around rebars, the change of the water and chloride content along with the delamination around rebar provide the basic condition for using of GPR to detection rebar corrosion. Different GPR signatures may be used for detecting internal corrosion of steel reinforcement within the concrete. Moisture and dissolved chlorides within the concrete attenuate the radar signals that are reflected from embedded rebar [65]. They also decrease their average velocity of the reflected signal resulting in increased arrival times. Generally, lower relative reflection magnitudes and greater travel times are indicative of greater corrosion or deterioration of rebar [66–68], seeing Figure 5. the amplitude of rebar reflection in sound section is strengthener the amplitude of the corrosion or deteriorated section.

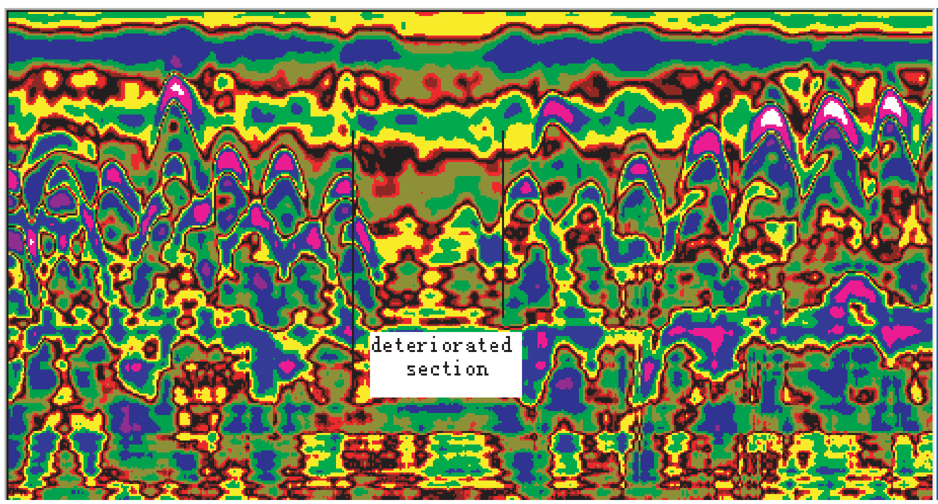


Figure 5: Example GPR data displaying from good rebars and carrion rebars.

Narayanan et al. [69] analyzed rebar reflection features to extract information regarding the corrosion state, a threshold level [70] was determined to differentiate between good and corroded rebars. The variance simulations helped to determine the reflectivity of the corroded rebar. Hubbard et al. [71] reported that the radar amplitude data of rebar reflection had the potential to indicate whether the corrosion had occurred. GPR method hold potential for direct and early detection of reinforcing bar corrosion, and that the combined use of GPR and electrical impedance techniques for assessing reinforcing bar corrosion state merits further study.

The location and cover depth of reinforcing steel in concrete structures has a great effect on the condition of that structure. A thin cover depth would result in rapid reinforcement corrosion, and therefore lead to early deterioration.

Rebar corrosion can result in cracking and spalling of the concrete cover and decreasing load-carrying capacity of concrete, so it is important to detection the corrosion at its early time, but for the most detection method used currently are destructive or time consuming, GPR is a potential method for direct and early detection of rebar corrosion, but most of this are carried out in laboratory, some are implement in site successfully combined with conventional method. The threshold of reflection amplitude used to discriminate the good and corroded rebar is different from on project to another and is influenced by many factors such as the water and chloride content of rebar cover and the type of the concrete in which the rebar are embedded. So there need further study before the GPR is used to detection rebar corrosion universally.

5. AUTOMATIC DETECTION

GPR displays are usually either manually scaled and interpreted, or stored and subsequently processed off-line. It require considerable operator skill, experience and time to produce a reliable end result. The processing aids that have been developed to aid in data interpretation are generally computationally expensive systems inadequate for on-site application. As GPR is becoming more and more popular as a shallow subsurface mapping tool, the volume of raw data that must be analyzed and interpreted is causing more of a challenge. There is thus a growing demand for automated subsurface mapping techniques that are both robust and rapid.

In the literature, there are still few published works dealing with the automatic detection of patterns associated with buried objects. In [72], the authors proposed also a method for extracting hyperbolic signatures of buried objects and hence estimating their position. In [73], the detection process is subdivided in three mainstages: 1) preprocessing step to reduce noise and undesired system effects; 2) image segmentation with an artificial neural network classifier to identify areas potentially containing object reflections; and 3) Hough transform to detect hyperbolic patterns. In [74], some preprocessing steps aiming at enhancing the signature of buried targets are implemented. Then, automatic image interpretation is carried out by a detector based on artificial neural networks. In [75], the authors applied a fuzzy clustering approach to identify hyperbolas from GPR images beforehand de-noised.

T. C. K. Molyneaux [76] examined the capability of three-layer, fully connected networks to detect the presence of a bar, the size of a bar, and the depth of a bar and demonstrated that the use of a neural network approach to interpret complex sub-surface radar results of embedded reinforcing bars is promising.

W. Al-Nuaimy and S. Shihab [77–81] has developed many automatic detection and interpretation method for GPR such as neural network techniques.

M. R. Shaw [52] used a neural network approach to automate and facilitate post-processing procedure and presented a novel technique for the estimation of the diameter of reinforcing bars. The results show that data taken with the transducer axis parallel and then orthogonal to the bar can be analysed by means of a MLP neural network to effectively estimate the diameter of embedded steel reinforcing bars.

M. R. Shaw [82] studied the use of a neural network approach to automate and facilitate the post-processing of ground penetrating radar results. The radar data is reduced to a simplified data set by using an edge detection routine. Signal reflections from reinforcing bars displaying a hyperbolic image format are detected using a multi-layer perceptron (MLP) network with a single hidden layer containing 8 nodes to recognize a simplified hyperbolic shape. The results showed that the use of a MLP neural network approach could be quite effective in automating the identification and location of embedded steel reinforcing bars from a radar investigation.

Francesco Soldovieri [83] exploit a linear inverse scattering algorithm in frequency domain based on the Born Approximation (BA); it allows to obtain satisfactory and reliable results in terms of localisation, sizing and shape of the buried objects and is computationally much more effective than nonlinear algorithms.

Edoardo Pasolli [84] proposed a novel system to identify and classify buried objects from GPR imagery using Genetic Algorithms and Support Vector Machines to detection and Classify Buried Objects.

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