A Pattern Recognition System for Extracting Buried Object Characteristics in GPR Images

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ABSTRACT

The development of non-invasive techniques to explore and retrieve information from underground has shown in the last years a growing interest related to different application fields, such as oil and gas exploration, geology, conduits and pipes location, and archaeology. Depending on the application, an appropriate sensor is used for imaging the underground. For the problem of detecting buried objects at small depth, which is the focus of this work, the most frequently used technique is based on the ground penetrating radar (GPR). This technique consists in the transmission and reception of electromagnetic waves by means of which it is aimed at achieving an exploration depth of few meters with a resolution of several centimeters. Typically, the interpretation of the large amount of acquired and stored GPR data requires a human operator with high levels of skill and experience, involving thus high costs in terms of time and money. As a consequence, these cost problems have encouraged a growing demand for the development of (semi-)automated subsurface mapping techniques that are both robust and rapid.

In general, the automatic analysis of buried objects implies the extraction of several characteristics associated with these objects, which raise the following four main methodological issues: 1) object detection and localization; 2) object material recognition; 3) object dimension estimation; and 4) object shape estimation. Till now, most of the research activity has been focused on the object detection and localization issue, while the other issues have been occasionally dealt with.

In a previous work, we proposed an automatic system aiming at solving the object detection and material recognition issues through a pattern recognition approach [1]. In this paper, we extend the processing capability of this system to the estimation of buried object dimension.

While in our work no constraint is imposed on the object shape, in the literature, the few works dealing with the object dimension estimation are only referred to buried objects having cylindrical shapes. For instance, in [2], the authors implemented a curve-fitting procedure specifically developed for hyperbolic signatures capable of estimating cylindrical object radius. The same problem is faced in [3] by a technique based on the generalized Hough transform. In [4], three different techniques for object radius estimation are proposed: the weighted least squares method, the recursive Kalman filter technique and the maximum likelihood method.

Our system is subdivided in five main successive phases: 1) pre-processing, 2) segmentation, 3) object detection, 4) material recognition, and 5) dimension estimation. The pre-processing procedure is implemented for: i) reducing noise; ii) eliminating the undesired presence of the ground surface echo; and iii) compensating propagation losses. In the second phase, the resulting pre-processed image undergoes two other processing stages. In the first one, a modulus operator is applied to compensate for phase inversions, which are generated by the presence of objects with particular dielectric characteristics in the subsoil. After that, the image is thresholded to discriminate between objects and the background. This binarization operation is implemented by means of the Kapur's thresholding technique. The object detection phase allows identifying the targets in the obtained binary image. This is done by means of a search of linear and hyperbolic patterns representing potential targets. This issue is viewed as a matching problem in which it is looked for the set of best

patterns fitting the content of the image. It is solved through a genetic optimization framework, where the chromosome models pattern apex position and curvature coefficient. The adopted fitness function is the Hamming distance between the content of the binary image and the image encoded by the candidate chromosome. In the fourth phase of the system, we intend to estimate the material type of the identified objects. This is made by means of the state-of-the-art support vector machine (SVM) classifier. For feeding the SVM classifier, a set of amplitude features is extracted from the object in the image by means of windowing, averaging, and normalizing operations. Finally, the last phase has the purpose of estimating the dimension of the detected objects. This problem is viewed as a regression issue where it is aimed at reproducing the relationship between a set of opportunely extracted features and the object dimension. The feature extraction process consists in considering this time unnormalized amplitude features in addition to three other features derived from the previous processing phases. They are: 1) the object depth (w.r.t the ground surface); 2) the curvature value associated with the detected hyperbola; and 3) the material type. The regression task is performed by means of a Gaussian process (GP) regressor [5]. GP regression formulates the learning of the regressor within a Bayesian framework, where the regression model is derived by assuming the model variables follow a Gaussian prior distribution encoding the prior knowledge about the output function. One of its interesting properties, which gives it a key advantage over traditional regression methods, is the possibility to tune the free parameters of the model in an automatic way.

To validate experimentally this methodological extension to our system, i.e. its capability to estimate the dimension of buried objects, we numerically generated GPR images by using the electromagnetic simulator GprMax [6] and by varying the number of buried objects as well as their position, size, shape and material type. We fixed the signal frequency at 400 MHz, the transmitter-receiver distance at $0.66\lambda_0$ (being λ_0 the wavelength of the electromagnetic wave) and the GPR position at $1.32\lambda_0$ (i.e, 1 m) from the ground. We introduced thousands of scatterers with random spatial and intensity distribution to represent the clutter in the propagation medium. We also added to the images a random Gaussian noise with different intensity. In general, the obtained experimental results show that the proposed system yields a promising accuracy in terms of object size estimation even when buried objects are close to each other.

Keywords: Buried objects, feature extraction, Gaussian processes, ground penetrating radar, pattern recognition.

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