Automatic Detection and Classification of Buried Objects in GPR Images using Genetic Algorithms and Support Vector Machines

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ABSTRACT

The development of noninvasive techniques to explore and retrieve information about the underground has shown in the last years a growing interest by public as well as private entities 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. In particular, 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 skill and experience, involving thus high costs in terms of time and money. As a consequence, these cost problems have encouraged an increasingly growing demand for the development of (semi-)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 [1], the classical Hough transform is used in order to identify linear segments in the image, representing transitions between layers of different electrical impedances. The authors proposed also a method for extracting hyperbolic signatures of buried objects and hence estimating their position. In [2], the detection process is subdivided in three main stages: 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 [3], 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 [4], the authors applied a fuzzy clustering approach to identify hyperbolas from GPR images beforehand de-noised.

In this paper, we propose a novel system to identify and classify buried objects from GPR imagery. The entire process is subdivided into four steps. In the first one, a preprocessing procedure is implemented for: 1) reducing noise; 2) eliminating the undesired presence of the ground surface echo; and 3) compensating propagation losses. Noise reduction is performed with a median filter, while the elimination of the ground surface echo is done by a simple average operation. A time-gain filter is used to compensate signal amplitude for losses due to spreading and attenuation. In the second step, the resulting preprocessed image is thresholded to discriminate between objects and background. This binarization operation, which allows to put under light the parts of the image
containing potential targets, is based on the fact that buried objects are generally associated with large amplitude echoes. It is implemented by means of the Kapur’s thresholding technique, which relies on the entropy maximization principle [5]. The third step of the system consists to identify the targets in the obtained binary image in a completely unsupervised way. This is done by means of a search of linear and hyperbolic patterns representing potential targets. This search problem is viewed as a matching problem in which it is looked for the set of best linear or/and hyperbolic patterns fitting the content of the binary image. It is solved through a genetic optimization framework where the chromosome models position of apex and curvature associated to the candidate pattern and the fitness function represents the Hamming distance between that pattern and the content of the image. At convergence, the genetic algorithm (GA) provides position of apex and curvature associated to the best hyperbola or linear segment fitting the image content. The curvature value permits to distinguish hyperbolas from linear shapes. Since the image may contain several hyperbolic/linear patterns, the GA is run in cascade several times, each associated with the search of a single pattern in the image. Once a pattern is identified, it is removed from the image to allow the GA for searching for another pattern in the next iteration. The process is stopped when a new extracted pattern is statistically incompatible with the previous ones. In the fourth and last phase of the system, we intend to estimate the material type of the identified objects. This is made in a supervised way by means of a support vector machine (SVM) classifier, which has proved effective in various application fields [6]. A set of features is extracted from the object in the image by means of windowing and averaging for feeding the SVM classifier.

To illustrate the performance of the proposed system, we numerically generated several GPR images using an electromagnetic simulator based on the finite-difference time-domain (FDTD) method. Simulations were designed by focusing on the archaeological application field. We fixed the signal frequency at 400 MHz, the transmitter-receiver distance at 0.66λ₀ (being λ₀ the wavelength of the electromagnetic wave) and the GPR position at 1.32λ₀ (i.e., 1 m) from the ground. In order to consider various archaeological scenarios, we generated different GPR images by varying the number of buried objects and their position, size, shape and material type. We introduced in the propagation medium some scatterers like clutter, with random spatial and intensity distribution. We also added to the image a random Gaussian noise with variable intensity. In general, the obtained experimental results show that the proposed system exhibits promising performances both in terms of detection of objects and material identification.

Keywords: Ground penetrating radar, detection of hyperbolic patterns, classification of buried objects, genetic algorithms, support vector machines.

REFERENCES