A Quantitative Analysis of Ground Penetrating Radar Method for Hydrogeological and Engineering Applications

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SUMMARY

To date, numerous researchers have conducted analyses of Ground Penetrating Radar (GPR) results using a traditional qualitative approach, directly interpreting radargrams without further analysis. Although anomalies are often clearly visible, there remains substantial potential for improvement in the analysis and interpretation of GPR data, which could yield more valuable information. In this study, we aimed to shift from the traditional approach to a more advanced procedure by analyzing GPR data quantitatively and employing statistical and machine-learning techniques for hydrogeological and engineering purposes. For hydrogeological applications, we attempted to estimate the hydrogeological properties of the subsurface through GPR measurements conducted in two distinct environmental settings: the coastal area of Guanyin Beach and the river area of the Wu River in Taiwan. For comparison purposes, Electrical Resistivity Imaging (ERI) surveys were also carried out along the GPR survey lines. We performed GPR scanning at 100 MHz and multi-channel ERI with 100 electrodes using the Wenner-Schlumberger configuration in both locations. Several processing steps were implemented to enhance the clarity of the acquired radargrams. Following that, machine learning (ML) and empirical models were employed to derive relative permittivity from the processed radargrams. Soil water content and the water table were then estimated based on the calculated relative permittivity. These results were subsequently compared with those obtained from ERI analysis and observation wells. The findings revealed an increase in soil water content with depth, ranging from 0.04 to 0.26 in river environments and from 0.07 to 0.35 in coastal environments. Both methods indicate groundwater tables at depths of 0.4 m for Guanyin Beach and 16.56 m for the Wu River, respectively. The consistent trend of increasing relative permittivity with depth, saturation level, and soil water content was confirmed through forward modeling simulation, affirming the efficacy of GPR data for hydrogeological investigations. For engineering applications, a 500 MHz antenna GPR scan was conducted on the paved concrete area to identify reinforcement bar (rebar) locations and lining boundaries. Seven radargrams were collected along the X-direction with 1-meter spacing, and six radargrams along the Y-direction with 6-meter spacing. The Fresnel Reflection Coefficient was used to identify boundaries between mediums with different electromagnetic properties in both A-scan and B-scan data. Subsequently, Two-Dimensional Forward Modeling (TDFM) was performed to simulate and verify signal behavior when detecting lining boundaries and anomalies such as rebar, voids filled with water, and voids filled with air. The Hilbert Transform (HT) was applied to extract the envelope or instantaneous amplitude, ensuring that the ML results were unaffected by phase differences within the same layer. Following this, unsupervised machine learning techniques, such as Hierarchical Agglomerative Clustering (HAC) and K-means algorithms, were employed to identify anomalies associated with rebar. To visualize the rebar distribution, a 3D GPR model with dimensions X=7 meters, Y=36 meters, and Z=2 meters was constructed. In conclusion, this study represents a significant advancement in GPR applications, demonstrating its enhanced capability in both hydrogeological and engineering assessments through quantitative methods and advanced data processing techniques.

Keywords: Ground Penetrating Radar, Quantitative Analysis, Hydrogeological, Engineering, Machine Learning