Development of a method to estimate one-dimensional distribution of dielectric constant using electromagnetic waves

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It is important to monitor water distribution under the ground near repository sites of radioactive waste. Water content in the ground and rocks can be evaluated via electromagnetic wave analysis. Electromagnetic wave analysis has advantages to evaluate water content for the following reasons: (1) The existence of pore water provides significant change in dielectric constant. (2) There is a relation between dielectric constant and degree of saturation. However, it is difficult to evaluate the distribution of dielectric constant in wave propagation direction by existing methods which are based on information of arrival time and amplitude of electromagnetic waves reflected from gap of dielectric constant.
This study presents a method to estimate the distribution of dielectric constant via electromagnetic wave analysis. The proposed method consists of an unscented Kalman filter and a finite element method. The unscented Kalman filter is a nonlinear Kalman filter which can evaluate state values of a nonlinear system from observation signals with zero-mean Gaussian noise. In the estimation process, the nonlinear Kalman filter requires computation of nonlinear transform. In this study, the computation of a nonlinear transform corresponds to the FEM analysis of reflected electromagnetic waves for arbitrary distribution of dielectric constant.
The validity and performance of our proposed method have been confirmed by numerical and laboratory experiments. In numerical experiments, reflected electromagnetic waves computed by FEM are used as observed signals. The estimated distribution of dielectric constant is in good agreement with the correct distribution. In laboratory experiments, reflected waves measured by a ground penetrating radar (GPR) are used as observed signals. The estimation results are not well fitted with the distributions expected. One of the reasons is that finite element analysis doesn’t consider the effects of wave attenuation, and this problem is a future task of this study.

Keywords: Electromagnetic wave, Distribution of dielectric constant, Unscented Kalman filter

