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Numerical parametric study to classify and estimate pavement characteristics using GPR and machine learning methods

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INTRODUCTION

For more than four decades, civil engineers have been interested in pavement surface degradation. Infrastructure owners have regularly resorted to the preventive maintenance to ensure a high quality index of the infrastructure networks, regardless the effective cost of the processes. By characterizing the subsurface pavement layers to reach the origin of surface defects, destructive methods such as coring have been performed. Unfortunately, these methods are punctual and cannot be reproduced, and can't be reused. Among the notable subsurface pathologies, debonding due to shearing, tearing or sliding effects are clearly identified. To prevent such damage, a bituminous emulsion (tack coat) is applied between pavement layers. This allows to ensure a strong cohesion between the wearing course and the binder course that behaves as a monolithic block. It increases the life duration and integrity of the pavement structures. Nowadays, there is no tool to evaluate tack coat in situ using a non-destructive method. By using the electromagnetic (EM) wave propagation for road auscultation, Ground-Penetrating Radar (GPR) offers the advantage of being non-destructive, high efficiency technique, often contact-less, sensitive to variations in dielectric and geometric characteristics, ... And moreover, it doesn't use radioactive sources (Daniels, 2005; Balayssac et al., 2009; Villain et al., 2009).

Previous studies have shown that high-resolution measurement of physical and geometric parameters can be done at a shallow depth or near-surface (Fauchard et al., 2003; Ihamouten et al., 2011; Sun et al., 2015; Klotzsche et al., 2019; Todkar et al., 2019) and a high-resolution signal processing used on conventional GPR signals could detect and measure the dielectric permittivity of thin pavement layers around 2 cm (Le Bastard et al., 2014 et Sun et al., 2020). In spite of these methods' strong capacity, they remain limited and not always robust to detect weaker variations in dielectric characteristics in dispersive media with few centimeter depth. Recently, (Todkar et al., 2019) used machine learning methods to detect automatically debonding pavement zone. Thus, the aim of our research is to extend the use of these machine learning methods applied to GPR raw signals to identify tack coat defects throughout EM mapping of various structure. This paper focused on the preliminary numerical study to show the ability of this artificial intelligence method applied to a non-destructive technique to detect automatically anomalies with an in situ geolocation.

PROPOSED METHOD

Using the numerical code gprMax in 2D configuration (Giannopoulos, 2005) to simulate EM waves propagation by solving Maxwell equation using *Finite Difference Time Domain* (FDTD)

method, a very wide data base have been generated to simulate EM wave propagation in various pavement structures (figure 1a). The model parameters included geometric and dielectric properties that can vary on the wearing course, the binder course and the tack coat (figure 1b). Once the temporal signals are generated (A-scans), machine learning methods start the training process on a part of the data base, then it ends with the testing process on an unknown part of the synthetic data base allowing the classification of the tack coat characteristics on a map. Based on expertise team feedback on the use a bi-variate normal distribution law (Patel and Read, 1982), a realistic variable of thin subsurface tack coats is applied on a 50 m long and 5 m wide synthetic structures with an offset grid of 0.25m (figure 2a). Thus, the unknown (tested) data base of 4160 A-scans have been generated. In order to respect a ratio of 30 % for the test and 70 % for training, a new data base with 9707 A-scans corresponding to various geometrical and physical characteristics (thickness, permittivity, conductivity, ...) with realistic values was also generated. Among existing methods, the supervised machine learning methods like *Support Vector Machine* (SVM) find a hyperplane in an N -dimensional space (with N is the number of features) allowing distinctly classifies the data points. The idea is to maximize decision boundary by choosing a margin that will represent distance between the variables and the best line (Schölkopf et al., 1999).

The objective of the work presented in this paper is to detect automatically changes in A-scans due to tack coat characteristics in various pavement structures using GPR data processed using the optimum SVM kernel and their hyperparameters. The results will be presented as two-classes mapping.

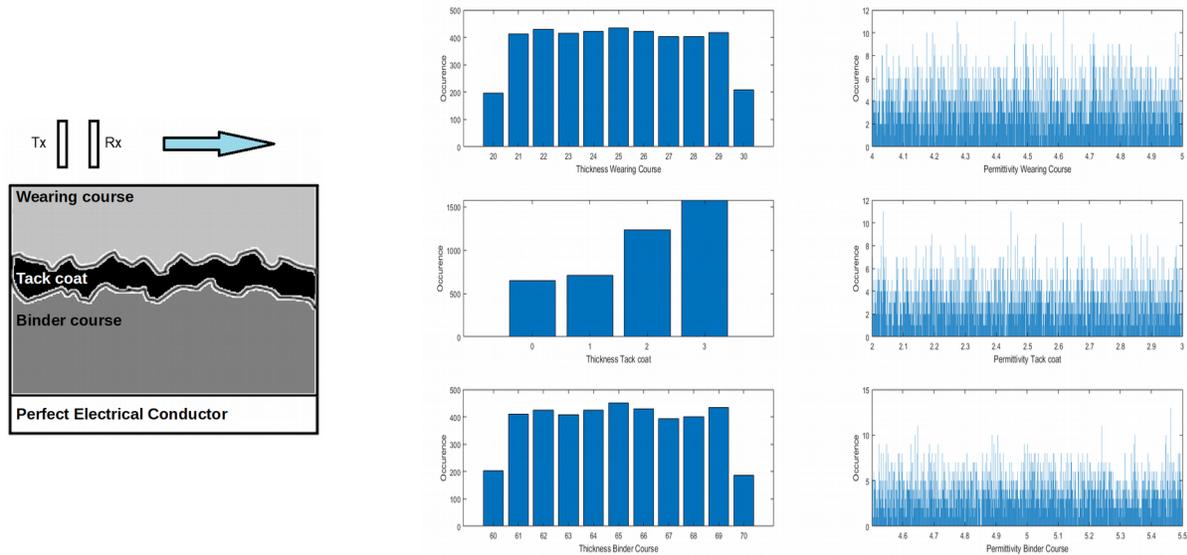


Figure 1 a) Example of homogenous and isotropic stratified propagation medium Wearing course / Tack coat / Binder course with variable parameters modeled using gprMax2D; b) Test data base distribution of thickness and permittivity for each layer

EM CLASS MAPPING

Two-Class Support Vector Machine (TCSVM) was used to split the data in two distinct classes (“adhered” and “non adhered” classes) (figure 2c). Then, *Multi-Class Support Vector Machine* (MCSVM) was used to classify in four different classes (absence, underdozed, standard dozed, overdozed) (figure 2d) with the hypothesis that there is a link between dosage and thickness of

the tack coat layer. Finally the *Support Vector Machine for Regression* SVR estimated the thickness with a regression approach (figure 2e). It's important to notice that SVM/SVR processing is done using a global approach no features used as input and the training is done on the whole raw A-scans).

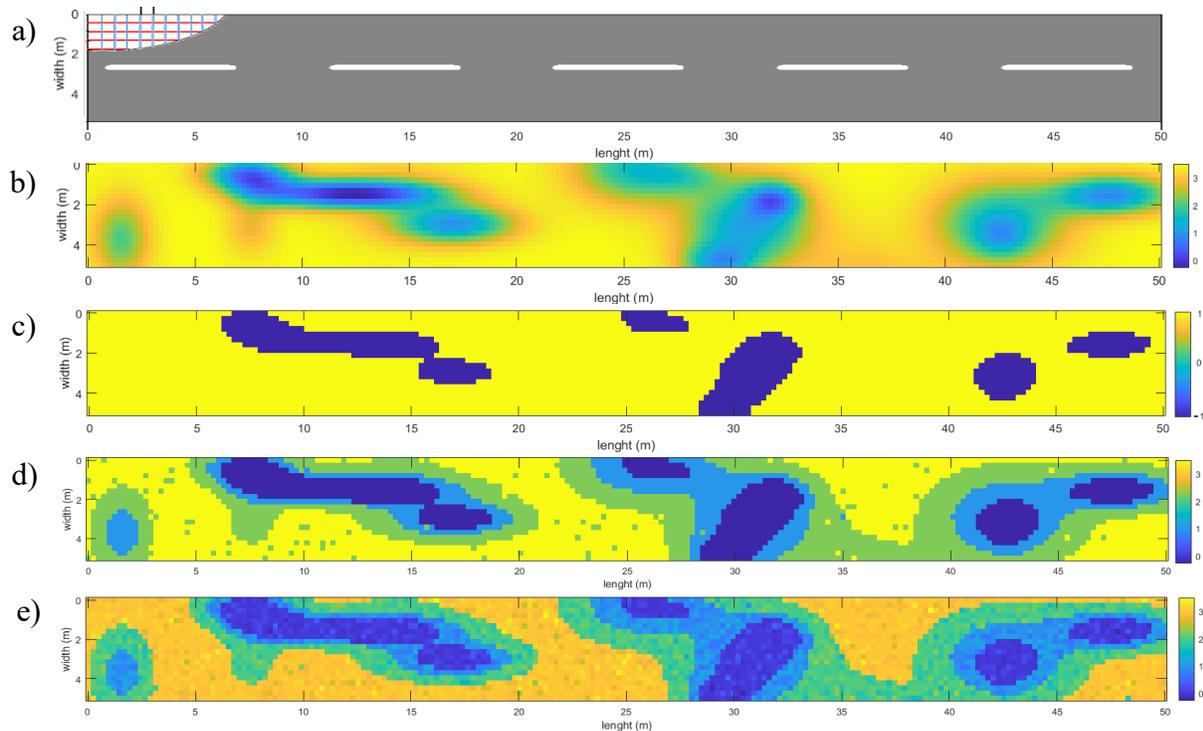


Figure 2 a) Grid of the synthetic pavement structure ; b) EM class mapping of ground truth with various states of tack coat ; c) Result of SVM with two classes: blue without tack coat and yellow with tack coat ; d) Result of MCSVM ; e) Result of SVR

RESULTS AND DISCUSSION

This study allowed for a classification by TCSVM machine learning to identify zones with or without tack coat (DSC > 99 %), even better to distinguish different thicknesses in four classes with the MCSVM (DSC > 98.5 %). Last but not least, The regression method with the SVR, allowed to estimate the thickness with great performances (RMSE = 0,28). In order to get closer to reality, an additive variable white Gaussian noise is also implemented. This allows to check the impact on the performance of the classifier (for SVM method) and the estimator (for the SVR method) and to evaluate the robustness of the algorithm.

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