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The use of machine learning method to classify electromagnetic characteristics of pavement tack coat

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Summary

Among the different non-destructive evaluation methods used on road infrastructures, Ground Penetrating Radar (GPR) is one of the most commonly used today. High-resolution methods are able to detect depth, cracks or significant debonding, but they remain limited and not very robust for identification of subsurface millimeter interfaces such as a tack coat. In this document, we propose to combine radar methods with two-class SVM supervised learning. A first trial on the fatigue carousel of Gustave Eiffel University (Nantes, France) has enabled us to validate the numerical methods we developed.

Introduction

Twenty-five million, that is how many kilometers of new road infrastructure should be added to ensure global transportation until 2050, according to the International Energy Agency (IEA). In order to prevent the degradation caused by growing traffic density, we have to be able to evaluate in advance the likelihood of structural or material failures appearing in the infrastructures (Khweir. and Fordyce, 2003). In order to maximize their durability, pavement structure in France uses the interface tack coat technique. This helps the complete multilayer structure act as one monolithic block, which minimizes mechanical strain (shear stress, monotonous twisting and so on) and in turn, minimizes the road structure degradation (Wang and Zhong, 2019 ; Diakhaté *et al.*, 2008). Diverse techniques help evaluating the state of the road: Destructive ones, where often the core of the pavement has to be drilled, and the physical and chemical properties have to be studied in a laboratory, and Non-Destructive ones, often using electromagnetic and mechanical waves propagation. Most of the time, the tack coat is a bitumen emulsion, spread mechanically, which makes it continuous and regular. Only after a breaking phase (evaporation of the water present in the emulsion) is the wearing course added, increasing the adhesion between the layers. To this day, the only guarantee we have for homogenous application of the bitumen emulsion is the performance of working machines.

Unfortunately, conventional sounding techniques (*i.e.* pulse radar) are not capable of evaluating the depth, density or permittivity of such a fine layer. A previous study showed that Full-Waveform Inversion (FWI) approach combined with SFR (Stepped Frequency Radar) radar techniques could effectively describe EM waves propagation through multi-layer coating by linking the tack coat's equivalent dielectric susceptibility with the bitumen emulsion quantity (Ihamouten *et al.*, 2017) (Figure 1). Indeed, the first results showed a monotonous evolution of the emulsion quantity in accordance with the estimated dielectric susceptibility for the transition area.

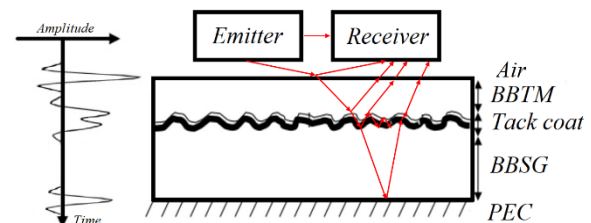


Figure 1 : Schematics of EM wave propagation modeling in a stratified environment

However the work on this subject is being hampered by the complexity of selectivity problems in the analytical model used, where diverse physical and geometrical characteristics have the same effects on the dielectric response of the stratified environment. This is the main reason for which the current research is being directed towards the treatment of GPR data by artificial intelligence. Supervised learning methods have been developed and optimized by French teams in order to extract the characteristics linked to structural or material anomalies (lifting, significant cracks and so on) (Todkar *et al.*, 2019). Our study will also use this methodology of inverse radar data processing by optimizing the two-class SVM method for classification of the bonding between wearing course and binder course in examples of road structures. The first part of this paper provides a succinct overview of the principle of synthetic signals digital validation, with some results of the parametric study, using gprMax. The second part presents and discusses the first

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results of experimental campaigns being implemented. This experiment takes place at the trials platform at Gustave Eiffel University in Nantes (France) where different coatings, placed in a full-scale fatigue carousel, are exposed to a large number of weights and degradation strains.

Methodology

Using gprMax 2D allows for the simulation of EM waves in modeled road structures by solving the Maxwell equations, through the FDTD method (Finite Difference Time Domain). Several bi-layer structures, with varying geometrical and physical parameters, have been modeled during a previous study. They were mainly composed of a wearing course and a binder course, integrating or not a millimeter layer representing the tack coat. This first digital approach was used to produce a model of a real road structure, 50 meter long and 5 meters wide, with a 0.25 meter depth (Figure 2a).

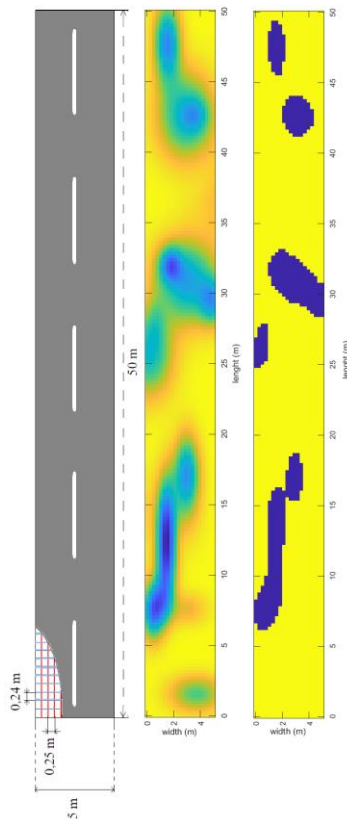


Figure 2 : a) Example of a bi-layer road structure model with a meshing relative to the positions of radar emission and reception sources on the nodes, b) Example of a model considered as ground truth regarding the depth variability of one tack coat over the whole structure, c) Result of inverse radar data in terms of two-class SVM classification.

Using normal bi-varied distribution, the tack coat has been spread on this zone, thus defining a ground truth on a large panel of radar signals for the training and test phases of our digital validation process (Figure 2b). This study aims to configure our automatic detection method around changes in the A-scans attributes, caused by a variation of the tack coat characteristics in a bitumen structure which is also variable. By using these different machine-learning algorithms developed around SVM, we could show a high performance in identifying significant time signal variations (A-scans) as dielectric contrast changes were accompanied by the apparition of echos. The SVM principle consists in placing a classification problem in a hyperplane where data is separated in several sets whose frontier is the furthest away possible from the data points (maximum margin). To reduce classification error, the cost function must be minimized. For this purpose, we used the Bayesian method's hyperparameters optimization. Two-class Support Vector Machine classification helped us separate the data in two categories: absence (in blue) or presence (in yellow) of a tack coat (Figure 2c) (Andreoli *et al.*, 2022). The learning phase was carried out on the global data set, *i.e.* by raw time signals analysis, without any preprocessing or features extractions. This digital study helped us conclude that it was possible to identify a healthy zone, in terms of tack coating, from one that presented defects. We then adapted our methods for a road structure placed in the fatigue carousel, whose formulation was known.

Experimental data

The Gustave Eiffel University in Nantes (France) has used for 40 years a fatigue carousel for experimentation. The circuit is a device used for accelerated testing on road structures, and allows to test real structures under variable weights (65 kN on single or twin axle, tandem or tridem) and variable rotation speeds (up to 100 km/h). In total, the track is 120 meters long and 6 meters wide and can reproduce the structural aging of a road under traffic, in an accelerated way (Figure 3).



Figure 3 : Fatigue carousel at the Gustave Eiffel University (Nantes)

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During trials relative to this study, a 60 meters long and 3,5 meters wide road structure has been put in place, comprised of 5 sections with and without a tack coat (Figure 3):

- Section S1a (12 meters): BBMA 0/10 (5 cm) / BB (5cm) with 300 g/m² emulsion,
- Section S1b (11 meters): BBMA 0/10 (5 cm) / BB (5cm) without emulsion,
- Section S2a (11 meters): BBSG 0/10 (6 cm) / BB (4cm) without emulsion
- Section S2b (11 meters): BBSG 0/10 (6 cm) / BB (4cm) with 300 g/m² emulsion,
- Section S2c (16 meters): BBSG 0/10 (6 cm) / BB (4cm) with 300 g/m² emulsion.

The goal here is to apply the methodology validated in a digital setting on gprMax to this road section whose formulation and state were controlled. Areas S1a, S2b and S2c have a tack coat (representing 300 g/m²) contrary to areas S1b and S2a, which will help verify the two-class SVM method. Moreover, the structure change in the wearing course will test the algorithm's robustness. The fatigue carousel simulates the aging of the road, this first study was done before it was switched on, *i.e.* on new pavement, and the results presented in this paper correspond to T₀ of the overall study. Current loading cycles (50k, 100k, ... rotation cycles) will validate our methodology while the weights and speeds evolve, and so, degrade the structures in the fatigue carousel. An important data basis will thus be constituted, involving training and testing at different levels of track wear; and then inverted.

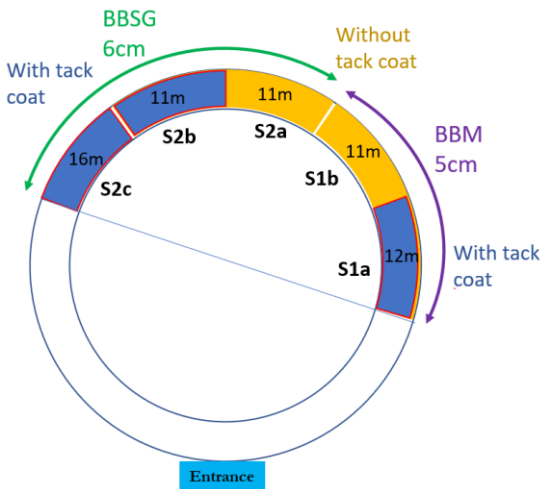


Figure 4 : Schematics of the different sections realized on the circuit

The results presented here were obtained using a pulse radar (SIR4000 GSSI) with antennas on different frequencies (2.6 GHz, 1.5 GHz, 900 MHz and 350 MHz). More than 5 pulse

radars and frequency hopping radar devices have been used for the overall study but their results aren't presented in this paper. With 50 A-scans per meter, we could capture an important data basis, which was necessary to feed the machine learning algorithm we had developed. Six profiles were created (4 longitudinal profiles, at P1=0.8 m from the inside edge, P2=1.5 m, P3=1.9 m and 2.65 m; 2 transverse profiles, at 3 m from the beginning of each section and 3 m from the end). The spacings were chosen according to the way the machine's wheels moved on the tracks (they followed a Gaussian curve centered on the P3 profile). This will give us several states of pavement deformation during the study.

The first classification of the data we acquired with the 2.6 GHz GSSI antenna has proven that the algorithms developed and optimized during the parametric digital study show very good first results regarding *in situ* data measures (on real pavement). The method identifies clearly the areas with and without tack coat and runs an automatic classification. Looking at Figure 5, the overlap area between S1a (with tack coat) and S1b (without tack coat), we can detect precisely the presence of the interface, and thus, the ability of our method to produce automatic classification by treating raw data that wasn't initially present in the training basis.

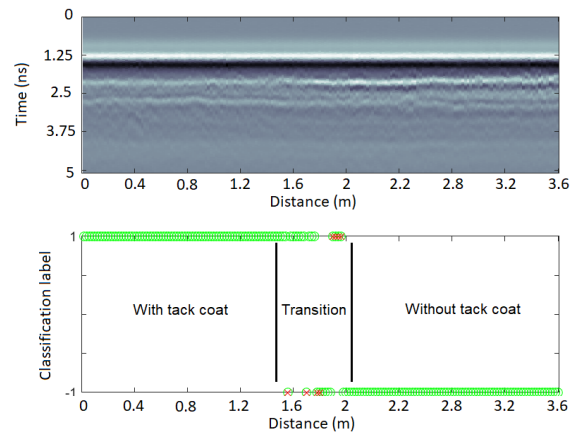


Figure 5 : a) Example of B-scan of the profile P1 at the overlap between the areas S1a and S1b of the circuit, b) Example of classification results (with or without tack coat) by the two-class SVM

		Predicted Class	
		-1	1
True Class	-1	TP 891 84.8 %	FP 160 15.2 %
	1	FN 125 6.6 %	TN 1783 93.4 %

Figure 6 : Confusion matrix showing the classification results produced on the whole fatigue carousel

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This method's performances can be quantified for each A-scan using a confusion matrix (Figure 6). It classifies between True Positives (TP) : No tack coat, True Negatives (TN) : Presence of a tack coat, False Positives (FP) : false alarm and False Negatives (FN) : no detection.

These preliminary results allow us to extrapolate the classification results in the form of a cartography of the area we study, and to identify precisely the repartition of the tack coat, regardless of the surface layer and the structure geometry (Figure 7). DSC performances, around 90%, remain very acceptable and show, at this stage of the study, our ability to locate the areas where the tack coat is defective, from GPR measures.

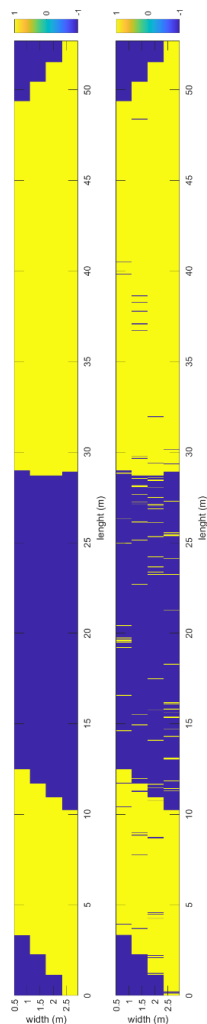


Figure 7 : a) Ground truth taking account of the presence of a tack coat on the 4 longitudinal profiles of the fatigue carousel, b) Results when inverting the radar data in terms of classification using the two-class SVM

Conclusions

The results of this study aimed to confirm the sensibility of electromagnetic waves to dielectric and geometric characteristics of the tack coat in the pavement, by inverse processing of radar data. The two-class SVM method shows very good abilities for identifying the areas with and without a tack coat. It is possible to identify precisely the presence of an interface and therefore, develop an automatic classification by processing raw data that was initially not present in the training phase. The experiment will be resumed and the results of the subsequent phases will be presented in the future works.

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