ROUGH THIN PAVEMENT THICKNESS ESTIMATION BY GPR

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1. INTRODUCTION

Ground penetrating radar (GPR) is a useful means of media sounding, which is widely used in road surfaces evaluation [1, 2]. In this context, the roadway is usually considered as compound of perfectly flat stratified interfaces. Then, the vertical structure and thickness of the roadway is deduced from radar echo detection and amplitudes estimation.

In this paper, the surface roughness of the pavement is taken into account in the GPR thickness estimation process, and compared with the case of neglecting the roughness of the pavement. First, the amplitudes of the first two echoes from the rough thin pavement are calculated with a rigorous electromagnetic method, namely the PILE method [3]. The frequency behavior of the echoes is then presented in the considered frequency band, $f \in [1.0; 3.0]$ GHz, comparatively to the ones with flat interfaces. Finally, the influence of the pavement roughness on the thickness estimation is investigated by using the Maximum Likelihood Method.

2. ECHO AMPLITUDES: FREQUENCY BEHAVIOR

In this section, the frequency behavior of the first two echoes s_1 and s_2 of a rough pavement is presented. To calculate the echoes within the frequency band $f \in [1.0; 3.0]$ GHz, the PILE (Propagation Inside Layer Expansion) method [3] is used. It is a Method-of-Moments based method which is able to compute rigorously each echo reflected by a flat or a rough layer.

The pavement under study is an homogeneous Ultra Thin Asphalt Surfacing (UTAS) of thickness $H = 20$ mm, overlying a rolling band of same general composition. The relative permittivities are $\epsilon_{r2} = 5$ and $\epsilon_{r3} = 8$, respectively, and the conductivities are $\sigma_2 = 5 \times 10^{-3}$ S/m and $\sigma_3 = 10^{-2}$ S/m, respectively. The upper surface Σ_A is characterized by a Gaussian height probability density function (pdf) with root mean square (rms) height $\sigma_{hA} = 0.8$ mm, and an exponential correlation function with correlation length $l_{cA} = 10.0$ mm. The lower surface Σ_B has the same characteristics, but with rms height $\sigma_{hB} = 1.6$ mm and correlation length $l_{cB} = 30.0$ mm. The two surfaces are uncorrelated.

To compute the numerical results, 1000 independent realizations of a Monte-Carlo process are generated, in order to simulate the variability of the received echoes. Indeed, for a practical scenario, the illuminated surface area is of the order of $100 - 200$ mm, which is not large in comparison with the two surface correlation length $l_{cA} = 10.0$ mm and $l_{cB} = 30.0$ mm. This implies that the received echo amplitudes depend on the location of the pavement where the measurement is made. As a consequence, in order to study the variability of the received echo amplitudes, a significant number of realizations must be generated.

Fig. 1 presents the frequency behavior of the real part of the first two echoes s_1 and s_2. The flat case is plotted in green full line, the mean value of the rough case in red circled dashed line, the mean value plus or minus twice the standard deviation of the rough case in magenta circled dash-dot line, and one realization of the rough case in blue dotted line with plus signs. The results highlight that as the radar frequency increases, the amplitudes of the backscattered echoes s_1 and s_2 decrease, because the layer (electromagnetic) roughness increases relatively to the wavelength. Moreover, for the lower frequencies $f \approx 1$ GHz, it can be seen that the difference with the flat case is relatively weak and could be neglected. On the contrary, for the higher frequencies $f \approx 3$ GHz, the relative difference with the flat case is significant and cannot be neglected any more, as it exceeds 10 percent for instance for s_2. Then, let us have a look at the consequences on the thickness estimation by GPR, with the Maximum Likelihood Method (MLM).

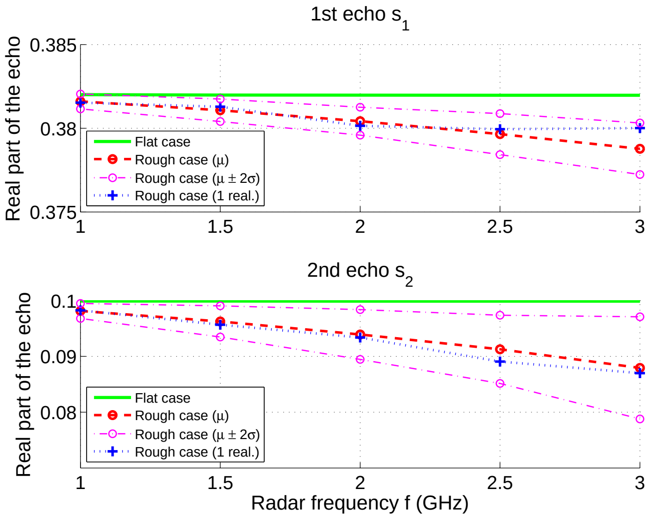

Fig. 1. Frequency behavior of the real part of the first two echoes s_1 and s_2

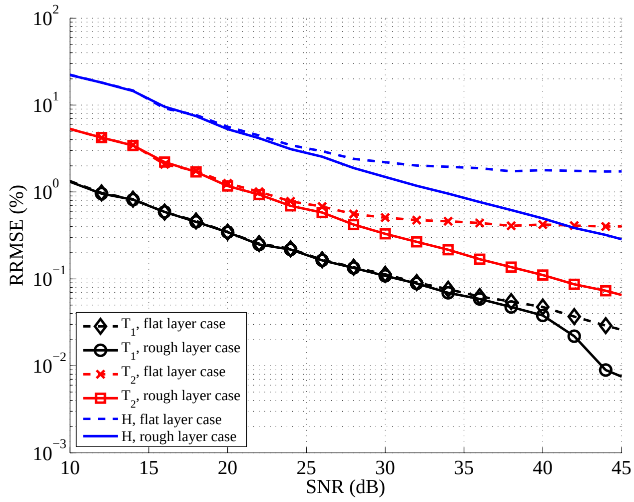

Fig. 2. RRMSE variations on the two estimated time delays $\hat{T}_1$ and $\hat{T}_2$, as well as on the layer thickness $\hat{H}$, vs. the SNR

3. THICKNESS ESTIMATION BY GPR

The process to determine the time delays of the first two echoes is explained in details in [2]. To perform time delay estimation (TDE), the MLM is used. An additive complex Gaussian white noise is considered to model the measurement uncertainties and the noise in the instruments. The radar pulse is a ricker pulse, defined as the second derivative of a Gaussian pulse. The data vector is made of 5 samples within the 2 GHz frequency bandwidth (see Fig. 1). The scenario under study is the same as described in the previous section. Thus, the data (i.e., the echo amplitudes s_1 and s_2) used to determine the time delays correspond to the realization plotted in blue dotted line with plus signs in Fig. 1.

Fig. 2 represents the relative root mean square error (RRMSE) variations on the two estimated time delays $\hat{T}_1$ and $\hat{T}_2$, as well as on the layer thickness $\hat{H}$, vs. the signal-to-noise ratio (SNR), for the frequency band $f \in [1.0; 3.0]$ GHz. First, for both flat and rough cases, it can be seen that the RRMSE decreases with increasing SNR. A difference between the flat and rough cases is observable in $\hat{T}_1$ for SNR higher than 40 dB, in $\hat{T}_2$ for SNR higher than 25 dB, and in $\hat{H}$ for SNR higher than 25 dB.

As a consequence, taking the roughness of the surfaces into account makes it possible to (significantly) increase the performances of the algorithm for moderate to high SNR. Thus, in the context of high SNR, it is important to take the roughness into account in the data modeling to obtain very low RRMSE, and this modeling allows in this case an even better precision of the thickness estimation. On the other hand, for low SNR and/or for a first estimate of the pavement thickness, these results confirm that taking the surface roughness into account is not necessary: this phenomenon can be neglected in this other context, as usually done in many previous studies.

4. REFERENCES

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