High time resolution GPR data processing for monitoring debonded pavement structures

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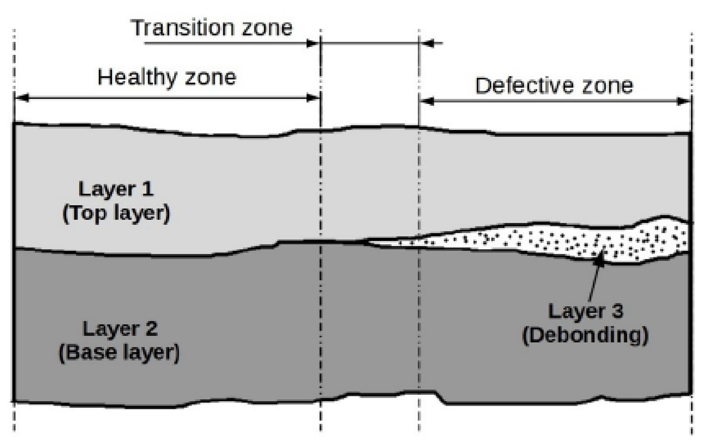
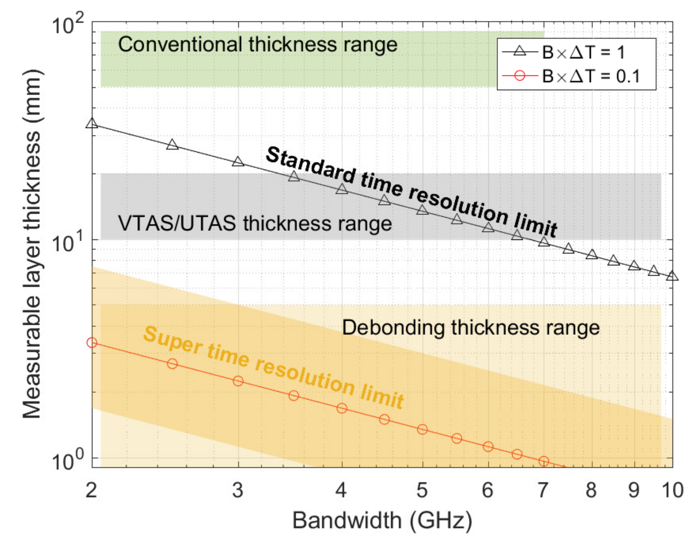
Context

- ANR ACIMP project: study thin interlayer debondings using NDT techniques *e.g.* GPR
- Debondings ⟶ road surface defects *e.g.* cracks

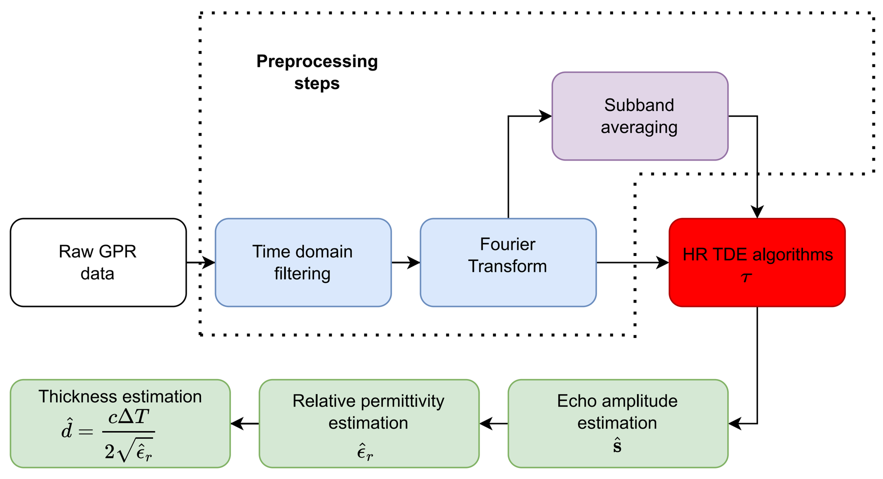




- Conventional GPRs
  ⇓
  limited time resolution
- Advanced processing
  ⇓
  improved resolution [1]

Objectives: Characterize (in terms of thickness and permittivity) and monitor the evolution of thin debondings ($\leq$ 1 cm) using UWB ground-penetrating radar (GPR) systems + advanced time delay estimation (TDE) methods

Methods and materials

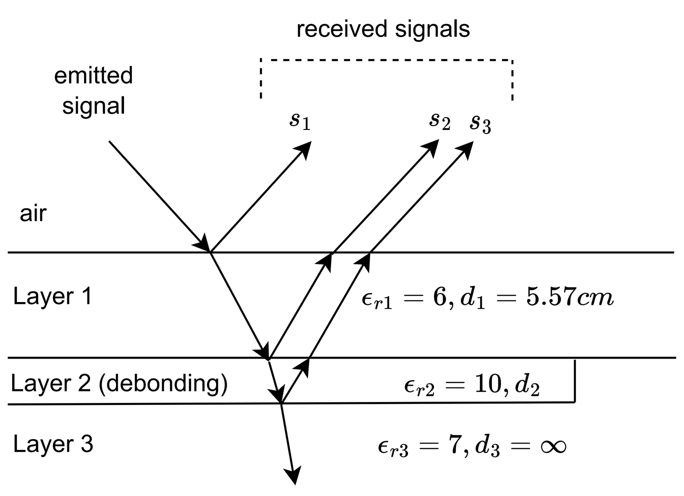


Steps proposed for debonding characterization and monitoring.

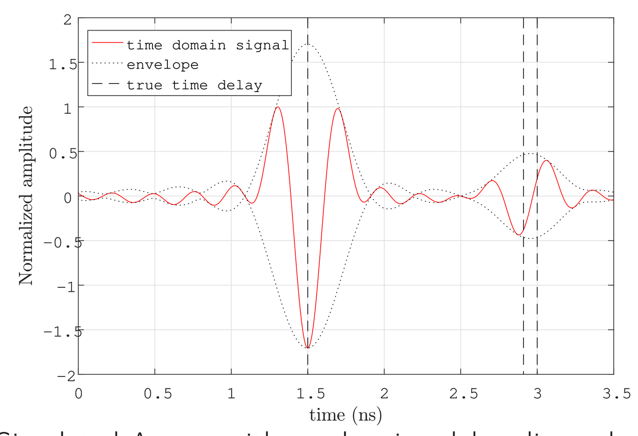
- 5 processing steps
- TDE = bottleneck
- UWB GPR + subspace based (SB) TDE methods
- Existing (e.g. root-MUSIC) and proposed SB methods (e.g. PUMA)

Simulated data

- 1-D simplified analytical signal model (A-scan)
- s_2 & s_3 are overlapping (*i.e.*, $B\Delta T < 1$)



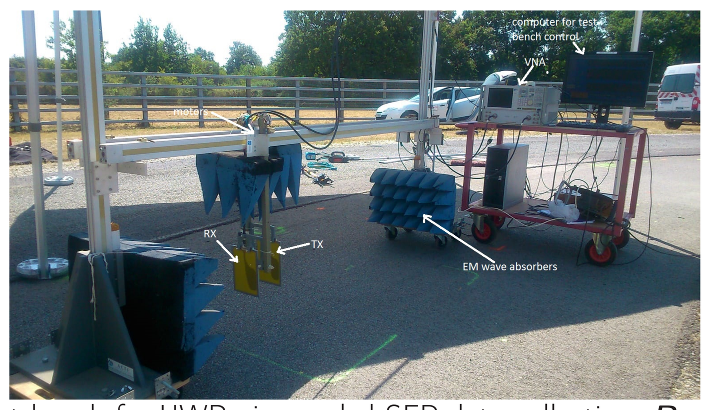
Layered pavement structure with debonding.



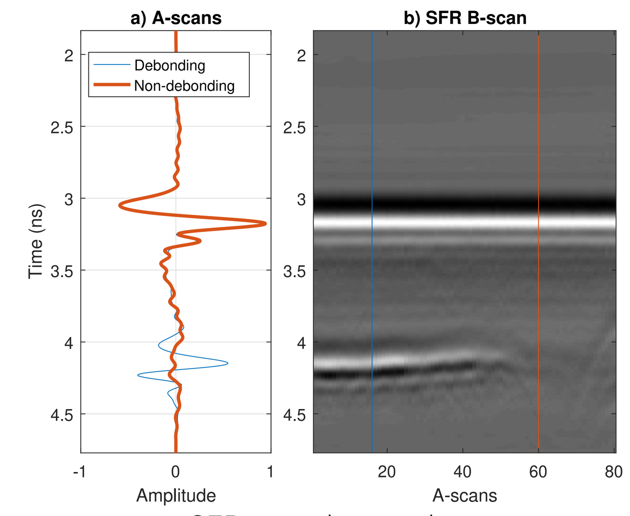
Simulated A-scan with overlapping debonding echoes.

Field GPR data

- UGE fatigue Carousel: data at 10 k & 300 k loading cycles
- Geotextile debonding (I-12, about 5.0 mm) [2]: A and B-scan data



UGE's test bench for UWB air-coupled SFR data collection, $B = 10$ GHz.

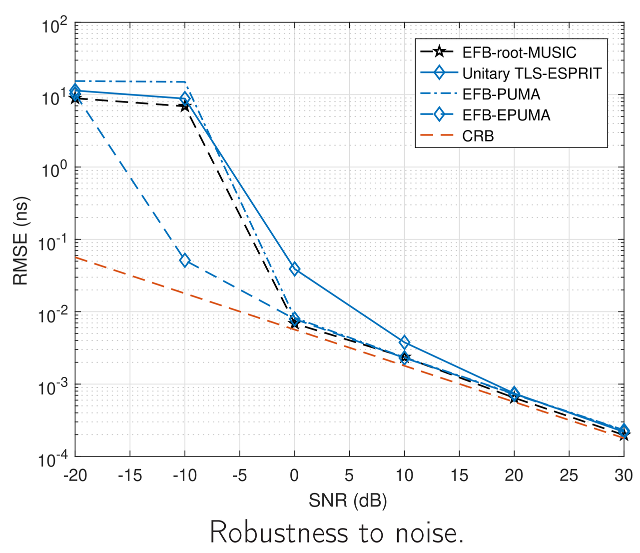


SFR time domain data.

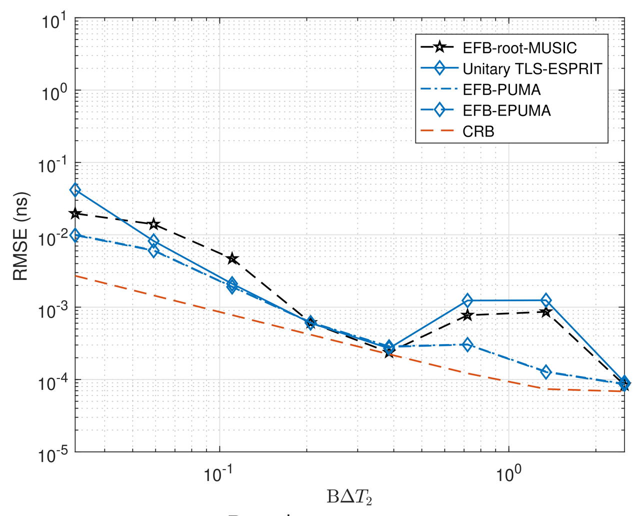
Results

Simulated data

- Evaluation of some selected TDE methods



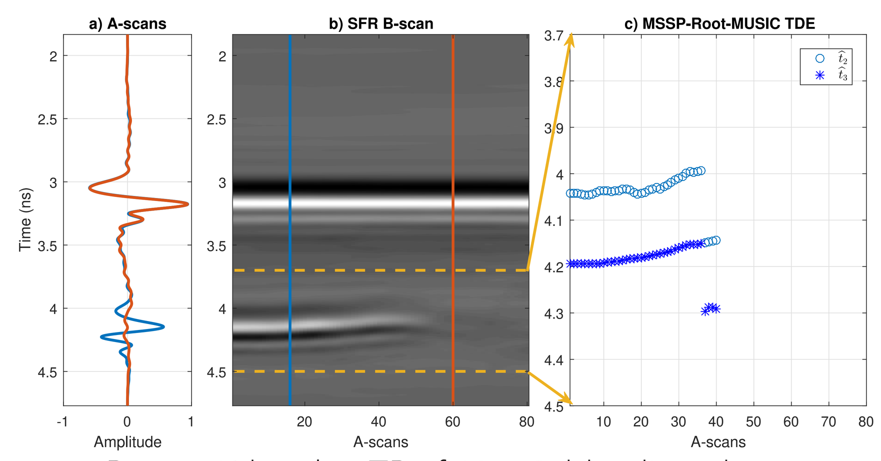
Robustness to noise.



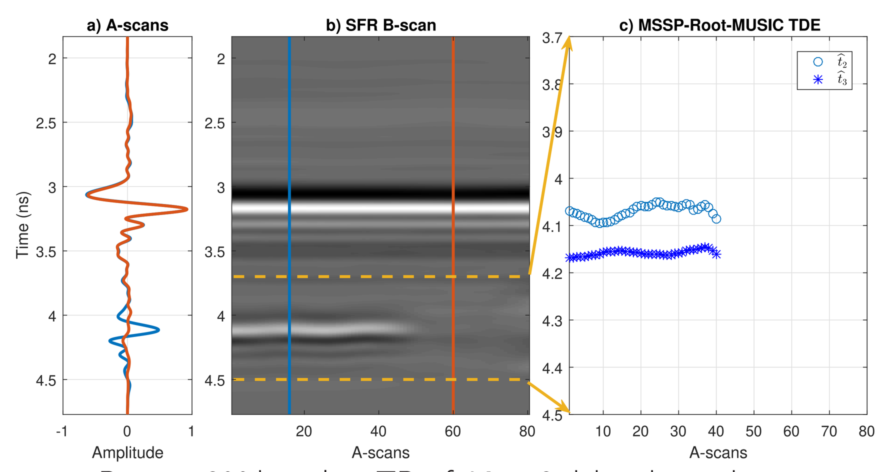
Resolution power.

Field GPR data

- TDE on the debonded zone (A-scan 1 to 40) with MSSP-root-MUSIC
- Debonding shrinks as we move from 10 k to 300 k cycles



Data at 10 k cycles: TD of $K = 2$ debonding echoes.



Data at 300 k cycles: TD of $K = 2$ debonding echoes.

- Thickness and permittivity estimates obtained after applying various TDE methods on one A-scan in the debonded zone (*e.g.* A-scan 16)

Algorithms	$\Delta \hat{T}_2$ (ns)	$\hat{\epsilon}_{r,2}$	$\hat{d}_2$ (mm)
EMSSP-root-MUSIC	0.156	4.000-1.506i	11.72
MSSP-root-MUSIC	0.152	4.392-1.479i	10.85
EMSSP-PUMA	0.147	4.272-2.007i	10.68
EFB-EPUMA	0.146	4.330-2.107i	10.49
PUMA	0.124	5.717-3.698i	7.77
GPUMA ($Q = 1$)	0.128	5.302-3.417i	8.36
EGPUMA ($Q = 1$)	0.150	4.190-1.865i	10.96

A-scan 16 at 10 k cycles: thickness and permittivity of the debonding.

Algorithms	$\Delta \hat{T}_2$ (ns)	$\hat{\epsilon}_{r,2}$	$\hat{d}_2$ (mm)
EMSSP-root-MUSIC	0.079	9.178-0.437i	3.92
MSSP-root-MUSIC	0.079	10.173+0.135i	3.70
EMSSP-PUMA	0.081	10.815-0.72i	3.68
EFB-EPUMA	0.081	14.058+0.964i	3.22
PUMA	0.101	9.036-3.958i	5.04
GPUMA ($Q = 1$)	0.102	8.866-4.05i	5.14
EGPUMA ($Q = 1$)	0.092	11.024-2.852i	4.13

A-scan 16 at 300 k cycles: thickness and permittivity of the debonding

- Debonding thickness at 300 k loading cycles is close to 5 mm (observed after coring [2])

Conclusion

- Proposed Novel HR TDE methods *e.g.* PUMA.
- Characterized thin artificial debondings from field air-coupled UWB GPR data using HR TDE methods, and then monitored their evolution.

Perspectives

- Explore alternative high resolution TDE methods that require little or no preprocessing.
- Perform TDE and characterization analysis of the whole existing GPR database over the UGE's fatigue carousel.

References

[1] B. Tchana Tankeu, V. Baltazart, Y. Wang, and D. Guilbert, "Puma applied to time delay estimation for processing gpr data over debonded pavement structures," *Remote Sensing*, vol. 13, no. 17, p. 3456, 2021.

[2] X. Dérobert, V. Baltazart, J.-M. Simonin, S. S. Todkar, C. Norgeot, and H.-Y. Hui, "Gpr monitoring of artificial debonded pavement structures throughout its life cycle during accelerated pavement testing," *Remote Sensing*, vol. 13, no. 8, p. 1474, 2021.

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