OUTILS ET MÉTHODES INTELLIGENTES POUR LES RADIO-SCIENCES

Analyse et extension des algorithmes DAS améliorés par Fermat pour l'imagerie micro-ondes

Analysis and extension of Fermat-Enhanced DAS Algorithms for Microwave Imaging

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Context – Qualitative microwave imaging have received increasing attention in recent years, particularly in biomedical applications, where fast and robust reconstruction methods are required. Among these, Delay-and-Sum (DAS)–based approaches remain a widely used reference for qualitative inverse scattering. This work explores a family of extensions and enhancements to DAS imaging, assessing their performance and robustness.

Method – DAS extensions include the multiplicative version (DMAS) [1], which provides greater robustness against noise, the Fermat version (FDAS) [2], which accounts for refraction laws at the object's outer interface *(red dashed circle in Fig. 1)*, and their natural combination FDMAS. These methods are compared across two scenarios with identical geometry but different permittivities. The same clutter removal method is used, an adaptation from the mean removal method [3] to the multistatic case. The quality of reconstruction is evaluated both visually and quantitatively using an accuracy metric, $\mathrm{Acc}(I) = \mathrm{mean}_p |I^\star[p] - I[p]|$. Additionally, the robustness of these methods to errors in source positions is assessed by comparing the mean and standard deviation of the accuracy across 50 random samples. The robustness to errors in the assumed dielectric permittivity is also examined. The frequency band is either $[2, 12]$GHz in the low-permittivity case *(see Fig.1)* or $[0.5, 4]$GHz in the high-permittivity and dispersive case. Data has been simulated on COMSOL for 2D domains with TM waves.

Results – In the absence of source position errors, FDAS outperforms the other methods *(see Fig. 1)*. However, introducing errors in the source positions causes the accuracy of DAS, DMAS, and FDAS to drop by 7-10%, while FDMAS experiences only a 2% decline. Furthermore, Fermat methods result in lower variance on the accuracy. The accuracy as a function of the assumed medium permittivity clearly shows that multiplicative methods tend to smooth the accuracy-permittivity curve, thereby reducing the algorithm's dependence on this parameter. Hence FDMAS shows interesting properties to remain performant with experimental noisy data.

Future work – The next step is to explore potential bridges between qualitative and quantitative imaging approaches. In this context, DAS-based methods can serve as initialization in iterative reconstruction frameworks, aiming to enhance image fidelity while keeping computational requirements practical. A forward model combining a DAS-like incident field and Born approximation-like scattered field could reproduce the simulation results with less than 15% $L2$-error compared to simulated fields, in a significantly reduced computational time (order of a second on a desktop computer).

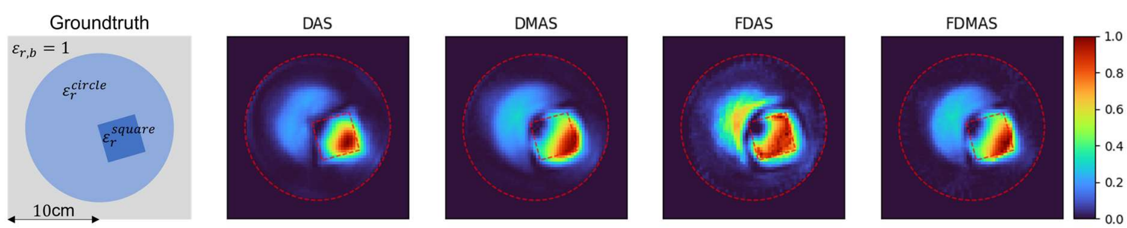

Figure 1: Reconstruction with the mentioned methods: $\varepsilon_r^{circle} = 3.12, \varepsilon_r^{square} = 5.74$. The red dashed line represents the true geometry. A total of 36 sources are uniformly distributed along a circle of radius 14 cm.

References

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