The 8th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2022
5 – 9 June 2022, Oslo, Norway

Parametric study of ultrasonic wave propagation in 3D-printed microstructures using the discontinuous Galerkin FE method

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Key Words: *3D-Printing, Wave Propagation Simulation, Discontinuous Galerkin FEM, Optimization*

Additive manufacturing has opened the possibility of creating anatomical twins that mimic the desired properties of the target organ for patient-specific rehearsal and physicians’ advanced training. These anatomical twins can improve the ability of surgeons by allowing them to practice specific surgical operations to reduce the risk of error or failure. Nowadays, several operations such as catheter-based endovascular procedures, are guided by real-time medical imaging techniques such as ultrasonography. Therefore, it is important that the printed organ replicates the ultrasonic signature of a human organ, which depends on the 3D-printed microstructure and the properties of the constituent materials.

In this study, we use numerical simulation to study the ultrasonic wave propagation in the printed organs, considering in detail the microstructure of the printed material. Nevertheless, this numerical simulation is very expensive due to the heterogenicity of the microstructure and the high frequency range of ultrasonic medical imaging (1-10 MHz). Therefore, the discontinuous Galerkin finite element method with capability of parallel calculation is used to overcome the challenge of calculation cost.

The final objective of this work is to improve the echogenicity of the 3D-printed organ by optimizing the characteristics of the microstructure. For this purpose, matrix-inclusion composite microstructures respecting the limits of the 3D-printer are studied in this work. Parametric studies are performed to quantify the effect of characteristics of the microstructure including the size, material properties, and distribution of the inclusions on the target parameters (such as echogenicity, attenuation coefficient, etc.). The feasibility of developing an optimization approach based on this detailed parametric analysis is also studied and discussed, which allows to define the microstructure having the best combination of the parameters that provides the most similar ultrasonic image to those of the real organs. This work is part of an ongoing collaboration between Biomodex and LMPS (Centralesupelec, Paris-Saclay University).

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