EVOLUTIONARY STRUCTURAL OPTIMIZATION

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Abstract

Topology optimization is a powerful technique used in engineering design to determine the optimal structure of a material while considering design constraints. Evolutionary Structural Optimization (ESO) is a topology optimization technique that has gained popularity due to its binarization method of the initial design domain, leading to uniformity of design and minimizing the chances of falling into local minima. This essay discusses the optimization dependency of initial problem design variables promoting the utilization of binarization methods in ESO for concurrent multiscale topology optimization. The essay also explores the BESO method, which allows the creation of materials within the design domain, increasing the robustness of ESO and minimizing local extrema.

Introduction

Topology optimization is a mathematical technique used in engineering design to determine the optimal structure of a material while considering design constraints. One of the most popular topology optimization techniques is Evolutionary Structural Optimization (ESO), which has gained popularity due to its binarization method of the initial design domain. ESO's philosophy is the direct removal of "inefficient material" leading to the optimal design of the structure. The cost function sensitivity is used to update the decision variables, and updating depends on the element sensitivity number obtained by differentiating the objective function, such that solid elements and soft elements have an elemental sensitivity and zero, respectively.

Optimization dependency of initial problem design variables promoting the utilization of binarization methods:

The design domain is either zero or 1 during the initialization phase, updating until the final design, promoting the utilization of binarization methods. This method reduces the volume to find the optimal solution as a binary topology. Performing ESO with this prescribed setting will lead to uniformity of design and limit the chances of falling into local minima. With covering almost all the design domains, ESO tries to reduce the volume to find the optimal solution as binary topology.

ESO has been used with many extensions for multi-physics problems. However, because ESO is limited by only permitting redundant material removal from the structure, and those materials cannot be reintroduced later, an oversized initial design domain is essential to ensure that the final design is adequately represented.

Bi-directional Evolutionary Structural Optimization (BESO) method

To address this issue, the Bi-directional Evolutionary Structural Optimization (BESO) method was introduced to allow the creation of materials within the design domain. This method increased the robustness of ESO and minimized the local extrema of the solution. BESO is an extension of ESO that allows the creation of material within the design domain, leading to a more robust and reliable optimization.

Conclusion

Topology optimization using Evolutionary Structural Optimization (ESO) is a powerful technique used in engineering design to determine the optimal structure of a material while considering design constraints. The binarization method of the initial design domain promotes the utilization of binarization methods and reduces the volume to find the optimal solution as a binary topology. The BESO method allows the creation of materials within the design domain, increasing the robustness of ESO and minimizing local extrema of the solution. These optimization techniques play an essential role in concurrent multiscale topology optimization, and their advancements have led to more efficient and cost-effective engineering designs.

References

1. Musaddiq Al Ali Toward Fully Autonomous Structure Design Based on Topology Optimization and Image Processing. In Proceedings of the Proceedings of the 6th IIAE International Conference on Intelligent Systems and Image Processing 2018; 2018; pp. 1–7.
2. Fujioka, M.; Shimoda, M.; Al Ali, M. Shape Optimization of Periodic-Microstructures for Stiffness Maximization of a Macrostructure. *Compos. Struct.* **2021**, *268*, 113873, doi:10.1016/j.compstruct.2021.113873.
3. Al Ali, M. Toward Fully Autonomous Structure Design Based on Topology Optimization and Image Processing. In Proceedings of the Proceedings of the 6th IIAE International Conference on Intelligent Systems and Image Processing; The Institute of Industrial Applications Engineers, 2018.
4. Musaddiq Al Ali, M.S. Toward Concurrent Multiscale Topology Optimization for High Heat Conductive and Light Weight Structure. In Proceedings of the 15th World Congress on Computational Mechanics (WCCM-XV) and 8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII); 2022; pp. 1–12.
5. Abass, R.S.; Ali, M. Al; Ali, M. Al Shape And Topology Optimization Design For Total Hip Joint Implant. In Proceedings of the Proceedings of the World Congress on Engineering; 2019; Vol. 0958.
6. Al Ali, M. Design Offshore Spherical Tank Support Using Shape Optimization. In

Proceedings of the Proceedings of the 6th IIAE International Conference on Intelligent Systems and Image Processing; 2018.

7. Al Ali, M.; Sahib, A.Y.; Al Ali, M. Design Light Weight Emergency Cot With Enhanced Spinal Immobilization Capability. In Proceedings of the 6th Asian/Australian Rotorcraft Forum & Heli Japan; 2017; pp. 1–11.

8. 藤岡みなみ; 下田昌利; Musaddiq Al, A.L.I. 所望変形を実現するマルチスケール構造の同時形状最適化. 計算力学講演会講演論文集 **2021**, *2021.34*, 3, doi:10.1299/jsmecmd.2021.34.003.

9. Al Ali, M.; Sahib, A.Y.; Al Ali, M. Teeth Implant Design Using Weighted Sum Multi-Objective Function for Topology Optimization and Real Coding Genetic Algorithm. In Proceedings of the The 6th IIAE International Conference on Industrial Application Engineering 2018; The Institute of Industrial Applications Engineers, Japan, 2018; pp. 182–188.

10. Ali, M. Al; Takezawa, A.; Kitamura, M. Comparative Study of Stress Minimization Using Topology Optimization and Morphing Based Shape Optimization Comparative Study of Stress Minimization Using Topology Optimization and Morphing Based Shape Optimization. In Proceedings of the The Asian Congress of Structural and Multidisciplinary Optimization; 2018.

11. Ali, M. Al; Ali, M. Al; Sahib, A.Y.; Abbas, R.S. Design Micro-Piezoelectric Actuated Gripper for Medical Applications. In Proceedings of the Proceedings of The 6th IIAE International Conference on Industrial Application Engineering 2018; The Institute of Industrial Application Engineers, 2018; pp. 175–180.

12. Al Ali, M.; Shimoda, M.; Benaissa, B.; Kobayashi, M. Concurrent Multiscale Hybrid Topology Optimization for Light Weight Porous Soft Robotic Hand with High Cellular Stiffness. In Proceedings of the Proceedings of the International Conference of Steel and Composite for Engineering Structures: ICSCES 2022; 2023; pp. 265–278.

13. Al-Ali, M.A.; Al-Ali, M.A.; Takezawa, A.; Kitamura, M. Topology Optimization and Fatigue Analysis of Temporomandibular Joint Prosthesis. *World J. Mech.* **2017**, *7*, 323–339.

14. Shimoda, P.M.; Ali, M. Al; Secondary, C.A.; Author, C.; Ali, M. Al; Shimoda, M.; Ali, M. Al Structural and Multidisciplinary Optimization Concurrent Multiscale Multiphysics Topology Optimization for Porous Composite Structures under Hygral Loading.

15. Fujioka, M.; Shimoda, M.; Al Ali, M. Concurrent Shape Optimization of a Multiscale Structure for Controlling Macrostructural Stiffness. *Struct. Multidiscip. Optim.* **2022**, *65*, 1–27, doi:10.1007/s00158-022-03304-y.

16. Ali, M. Al; Takezawa, A.; Kitamura, M. Comparative Study of Stress Minimization Using Topology Optimization and Morphing Based Shape Optimization Comparative Study of Stress Minimization Using Topology Optimization and Morphing Based Shape Optimization. **2019**.

17. Amoura, N.; Benaissa, B.; Al Ali, M.; Khatir, S. Deep Neural Network and YUKI Algorithm for Inner Damage Characterization Based on Elastic Boundary Displacement. In Proceedings of the Proceedings of the International Conference of Steel and Composite for Engineering Structures: ICSCES 2022; 2023; pp. 220–233.

18. Al Ali, M.; Al Ali, M.; Saleh, R.S.; Sahib, A.Y. Fatigue Life Extending For

Temporomandibular Plate Using Non Parametric Cascade Optimization. In Proceedings of the Proceedings of the World Congress on Engineering 2019; 2019; pp. 547–553.

19. Fujioka, M.; Shimoda, M.; Ali, M. Al Concurrent Shape Optimization for Multiscale Structure with Desired Static Deformation. *Proc. Comput. Mech. Conf.* **2021**, *2021.34*, 3, doi:10.1299/jsmecmd.2021.34.003 (in Japanese).

20. Shimoda, M.; Umemura, M.; Al Ali, M.; Tsukihara, R. Shape and Topology Optimization Method for Fiber Placement Design of CFRP Plate and Shell Structures. *Compos. Struct.* **2023**, *309*, 116729, doi:10.1016/j.compstruct.2023.116729.

21. Musaddiq Al Ali, M.S. Concurrent Multiscale Topology Optimization for Designing Displacement Inverter. In Proceedings of the 15th World Congress on Computational Mechanics (WCCM-XV) and 8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII); 2022; pp. 1–10.

22. Al Ali, M.; Shimoda, M. Toward Multiphysics Multiscale Concurrent Topology Optimization for Lightweight Structures with High Heat Conductivity and High Stiffness Using MATLAB. *Struct. Multidiscip. Optim.* **2022**, *65*, 1–26, doi:10.1007/s00158-022-03291-0.

23. Al Ali, M.; Shimoda, M. Toward Concurrent Multiscale Topology Optimization for High Heat Conductive and Light Weight Structure. In Proceedings of the 15th World Congress on Computational Mechanics (WCCM-XV) and 8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII); S. Koshizuka, Ed.; CIMNE, 2022; p. 12.

24. Torisaki, M.; Shimoda, M.; Al Ali, M. Shape Optimization Method for Strength Design Problem of Microstructures in a Multiscale Structure. *Int. J. Numer. Methods Eng.* **2023**, *124*, 1748–1772, doi:10.1002/nme.7186.

25. Abass, R.S.; Ali, M. Al; Ali, M. Al Shape And Topology Optimization Design For Total Hip Joint Implant. In Proceedings of the World Congress on Engineering 2019; 2019; Vol. 0958.

26. Al Ali, M.; Shimoda, M. Investigation of Concurrent Multiscale Topology Optimization for Designing Lightweight Macrostructure with High Thermal Conductivity. *Int. J. Therm. Sci.* **2022**, *179*, 107653, doi:10.1016/j.ijthermalsci.2022.107653.

27. Kato, T.; Fujioka, M.; Shimoda, M. Multi-Scale Shape Optimization Method for Designing a Macrostructure with Periodic-Microstructures Using Inverse Homogenization Method and H1 Gradient Method. *Trans. Japan Soc. Mech. Eng.* **2019**, *85*.

28. Al Ali, M.; Al Ali, M.; Sahib, A.Y.; Abbas, R.S. Design Micro Piezoelectric Actuated Gripper for Medical Applications. In Proceedings of the Proceedings of the 6th IIAE International Conference on Industrial Application Engineering, Japan; 2018; pp. 175–180.

29. Shirazi, M.I.; Khatir, S.; Benaissa, B.; Mirjalili, S.; Wahab, M.A. Damage Assessment in Laminated Composite Plates Using Modal Strain Energy and YUKI-ANN Algorithm. *Compos. Struct.* **2023**, *303*, 116272.

30. Benaissa, B.; Hocine, N.A.; Khatir, S.; Riahi, M.K.; Mirjalili, S. YUKI Algorithm and POD-RBF for Elastostatic and Dynamic Crack Identification. *J. Comput. Sci.* **2021**, *55*, 101451, doi:10.1016/j.jocs.2021.101451.

31. Irfan Shirazi, M.; Khatir, S.; Benaissa, B.; Mirjalili, S.; Abdel Wahab, M. Damage Assessment in Laminated Composite Plates Using Modal Strain Energy and YUKI-ANN Algorithm. *Compos. Struct.* **2022**, 116272, doi:https://doi.org/10.1016/j.compstruct.2022.116272.