Zhongyuan Liao (廖中源)

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Education

- **Hong Kong University of Science and Technology** — Hong Kong, China
  PhD in IIP (Smart Manufacturing), 2021–2024 — Supervisor: *Prof. Yi Cai* and *Mingming Fan*
- **South China University of Technology** — Guangzhou, China
  MPhil in Mechanical Engineering, 2018–2021 — Supervisor: *Prof. Yingjun Wang*
- **South China University of Technology** — Guangzhou, China
  BSc(Eng) in Mechanical Engineering, 2014–2018 — Supervisor: *Prof. Zhijia Xu*

Professional Experience

- **North Carolina State University** — Raleigh, USA
  Visiting Scholar in Department of Industrial and Systems Engineering, 2024 — Supervisor: *Prof. Yuan-Shin Lee*
- **Peking University** — Beijing, China
  Visiting Student in College of Engineering, 2024 — Supervisor: *Prof. Ke Liu*

Research Interests

- Topology/Shape Optimization
- Metamaterial Design
- Advanced Additive Manufacturing Techniques
- Reconfigurable Soft Robots
- Digital Twin
- AR/VR Technologies
- Internet of Things
- Human-Robot Interaction

Scholarships and Awards

- **Outstanding Paper Award of NAMRC51** — 2023
- **National Scholarship** — 2019, 2020
- HKUST Overseas Research Award — 2024
- Outstanding Graduate Student of Guangdong Province — 2021
- Postgraduate Scholarship — 2021-2024
- Meritorious Winner of COMAP's Mathematical Contest in Modeling (MCM) — 2017
- First Prize Winner in Guangdong Province of CUMCM (China Mathematical Contest in Modeling) — 2016
- School Scholarship (Triple) — 2015–2018

Refereed journal papers

[1] **Z. Liao** and Y. Cai, "AR-enhanced digital twin for human-robot interaction in manufacturing systems", *Energy, Ecology and Environment*, 2024.

[2] W. Wei, L. Zhang, **Z. Liao**, and Y. Cai, "Aerosol jet printing of advanced capacitive strain gauge for vibration monitoring of human body", *The International Journal of Advanced Manufacturing Technology*, 2024, Accepted.

[3] T. Li, **Zhongyuan Liao**, and Y. Cai, "Physical modeling for digital twin of continuous damping control damper", *Journal of Manufacturing Processes*, vol. 99, pp. 96–104, 2023, Presented at the 51st SME North American Manufacturing Research Conference, New Brunswick, New Jersey, USA, June 12-16, 2023. **Outstanding Paper Award of NAMRC51**.

[4] Y. Zheng, J. Xiang, **Z. Liao**, P. Li, X. Cai, Z. Chen, and J. Huang, "Hierarchical topology optimization with varying micro-structural aspect ratios", *Engineering Analysis with Boundary Elements*, vol. 156, pp. 34–47, 2023.

[5] **Zhongyuan Liao**, T. Li, Y. Wang, and Y. Cai, "Soft pneumatic actuator optimal design based on isogeometric analysis", *Manufacturing Letters*, vol. 35, pp. 55–63, 2023, Presented at the 51st SME North American Manufacturing Research Conference, New Brunswick, New Jersey, USA, June 12-16, 2023.

[6] J. Chen, **Zhongyuan Liao**, and Y. Cai, "Enhancing size perception with true-size viewing CAD plug-in and cloud-enabled AR APP", *Computer-Aided Design and Applications*, 20(6), 1128–1140, 2022.

[7] **Zhongyuan Liao**, J. Chen, and Y. Cai, "Reconfigurable soft robots based on modular design", *Computer-Aided Design and Applications*, 20(6), 1141–1153, 2022.

[8] **Zhongyuan Liao**, Y. Wang, L. Gao, and Z.-P. Wang, "Deep-learning-based isogeometric inverse design for tetra-chiral auxetics", *Composite Structures*, vol. 280, p. 114 808, 2022.

[9] Y. Wang, **Zhongyuan Liao**, S. Shi, Z. Wang, and L. Hien Poh, "Data-Driven Structural Design Optimization for Petal-Shaped Auxetics Using Isogeometric Analysis", *Computer Modeling in Engineering & Sciences*, vol. 122, no. 2, pp. 433–458, 2020.

[10] Y. Wang, **Zhongyuan Liao**, M. Ye, Y. Zhang, W. Li, and Z. Xia, "An efficient isogeometric topology optimization using multilevel mesh, MGCG and local-update strategy", *Advances in Engineering Software*, vol. 139, p. 102 733, 2020, **ESI Highly Cited Paper**.

[11] Y. Zheng, Y. Wang, X. Lu, **Zhongyuan Liao**, and J. Qu, "Evolutionary topology optimization for mechanical metamaterials with auxetic property", *International Journal of Mechanical Sciences*, vol. 179, p. 105 638, Aug. 2020.

[12] **Zhongyuan Liao**, Y. Wang, and S. Wang, "Graded-density Lattice Structure Optimization Design Based on Topology Optimization (in Chinese)", *Chinese Journal of Mechanical Engineering*, vol. 55, no. 8, p. 65, 2019, **2021 Best Paper Award**.

[13] **Zhongyuan Liao**, Y. Zhang, Y. Wang, and W. Li, "A triple acceleration method for topology optimization", *Structural and Multidisciplinary Optimization*, vol. 60, no. 2, pp. 727–744, Aug. 2019.

Refereed Conference Proceedings

1. **Zhongyuan Liao**, Wei W., Zhang L., Yi Cai*, "Sensor Fusion-based Parameterized Curve-driven Modeling for Digital Twin of Reconfigurable Soft Robot". *The 6th IEEE/IFToMM International Conference on Reconfigurable Mechanisms and Robots*, 2024.

2. **Zhongyuan Liao**, Yi Cai*, "Human-centric Five-dimensional Digital Twin Model: A Case Study in AR-enhanced Human-Robot Collaboration". Accepted by *the 2024 Flexible Automation and Intelligent Manufacturing International Conference.*

3. **Zhongyuan Liao**, Chen, J., Cai, Y., "Reconfigurable Soft Robots based on Modular Design" , *Proceedings of the 19th annual International CAD Conference, Beijing, China, July 11-13, 2022.*

Unrefereed Conference Paper

1. **Zhongyuan Liao**., Cai, Y., "An Augmented Reality-Based Digital Twin System for Enhancing Human-Robot Interaction in Manufacturing", Oral presentation. *2023 Annual International Conference for Chinese Scholars in Industrial Engineering, Guangzhou, China, August 10-12, 2023.*

2. **Zhongyuan Liao**., Wang, Y., "Multiple-accelerated isogeometric topology optimization method", Poster. *Proceedings of Chinese Congress of Theoretical and Applied Mechanics, Hangzhou, China, Summer 2019.*

3. **Zhongyuan Liao**., Wang, Y., "The topology optimization based on triple-accelerated method", Oral presentation. *Proceedings of 2018 National Conference on Solid Mechanics, Harbin, China, Winter 2018.*

Thesis

1. **Zhongyuan Liao**. AR-enhanced Digital Twin System for Reconfigurable Soft Robots. PhD Thesis. The Hong Kong University of Science and Technology.

2. **Zhongyuan Liao**. Research on Efficient Structure optimization Method based on Isogeometric Analysis. Master Thesis. South China University of Technology.

3. **Zhongyuan Liao**. Design of high-performance Variable density lattice Connecting rod Based on Topology Optimization. Bachelor Thesis. South China University of Technology.

Patents

1. Wang Yingjun, **Zhongyuan Liao**. A triple acceleration topology optimization method. C.N. Patent: CN109840348B, issued in 2023.

2. Wang Yingjun, Yang Yuhao, **Zhongyuan Liao**. The automatic construction method and system of editable model with equal geometric topology optimization results. C.N. Patent: CN112926207B, issued in 2022.

3. Wang Yingjun, **Zhongyuan Liao**. Software copyright: Isogeometric analysis software based on embedded domain reconstruction model (V1.0); Registration Number: 2021SR0045889, issued.

Research Program

- **Digital Twin Systems for Reconfigurable Soft Robots (2023-present)**
  In this study, we propose an innovative approach to constructing a digital twin (DT) system for reconfigurable soft robots in an augmented reality (AR) environment. Our approach utilizes armature-based methods to modify and reconstruct the digital twin of reconfigurable soft robots in the AR environment, allowing for continuous representation of their deformations. We identify three fundamental types of deformation patterns - stretching, bending, and twisting - and propose corresponding visualization patterns to represent these transformations accurately. Additionally, we employ a sensor fusion method to capture the soft robot's deformation as a parameterized curve, enabling more precise visualization in the AR environment. The proposed framework is implemented in the AR environment, providing immersive inspection and reconfigurable simulation for real-world soft robots, enhancing their adaptability and functionality.

- **Three-levels Digital Twin Systems for Human-Robot Interaction (2022-present)**
  This research focuses on the development of a novel Augmented Reality (AR)-based digital twin system for human-robot interaction in manufacturing settings, with the aim of improving efficiency, accuracy, and adaptability. A three-level approach to digital twin technology is introduced, comprising virtual twin, hybrid twin, and cognitive twin levels, each offering unique functionalities. An intuitive AR-based interface is created, enabling users to interact with the digital twin through natural gestures, thereby streamlining programming and control processes. A comprehensive human-centric user study is conducted to validate the efficacy of the proposed system in minimizing setup time, reducing errors, and enhancing overall productivity.

- **Data-Driven Shape Optimization Design for Auxetics Using Isogeometric Analysis (2019-2021)**
  This project implements a back-propagation neural network (BPNN)-based design framework for petal-shaped auxetics

using isogeometric analysis, and proposes a deep neural networks (DNN) framework for tetra-chiral auxetics shape optimization design. The highly nonlinear relation between the input geometry variables and the effective material properties is fitted by a data-driven method (i.e., BPNN, DNN), facilitated by the NURBS-based parametric modeling scheme with a small number of design variables. This enables an easy analytical sensitivity analysis, demonstrating high accuracy and efficiency. Optimal auxetic structures are produced using 3D printing and experimentally tested for their properties. The implementation is based on the collaboration between Matlab and TensorFlow.

- **Multiple Accelerated Methods for Mesh-based and Isogeometric Topology Optimization (2018-2019)**
  This research proposes multilevel mesh, effective iterative methods, and local-update strategies to accelerate computing efficiency in topology optimization. For mesh-based topology optimization, the method projects density from coarse to fine meshes to accelerate convergence, adopts an initial-value-based preconditioned conjugate-gradient (PCG) method to solve the equations of Finite Element Analysis (FEA), and decreases the number of updated meshes according to their density. This results in a 35%–80% reduction in computational time compared to the classical TOP88 code. For isogeometric topology optimization, where control points are the design variables, the method applies h-refinement to subdivide the mesh, adopts a Multigrid conjugate gradient method (MGCG) to solve the equilibrium equation, and reduces control points according to their density. This successfully reduces 37%–93% of computational time compared to unaccelerated cases. The multiple accelerated methods perform better in large-scale cases and have general applicability for topology optimizations based on either meshes or control points.

- **Graded-density Lattice Structure Optimization Design Based on Topology Optimization (2017-2018)**
  This research proposes a multiscale topology optimization method based on the homogenization method, which generates graded-density lattice structures according to actual loads to achieve optimal performance. The method combines MATLAB with ANSYS, where optimization is performed in MATLAB and FEA computing and modeling are conducted in ANSYS. The lattice structure is rebuilt using Rhinoceros. Compared with the beam-model-based lattice optimization method from commercial software HyperWorks, the proposed method achieves better performance in mass reduction and stress distribution. The feasibility of manufacturing the lattice structure is demonstrated through 3D printing.

Teaching

- **Teaching Assistant** at HKUST(GZ) Spring 2023
  Cross-disciplinary Research Methods I (UCMP 6010)
- **Teaching Assistant** at HKUST(GZ) Fall 2022
  Design for Additive Manufacturing (SMMG 6000A)
- **Teaching Assistant** at SCUT Spring 2019
  Fluid Mechanics

Internship

- *ZWCAD Co. Ltd*, Graphic algorithm Engineer, 2021
- *Guangzhou Tongda Auto Electric Co., LTD*, Mechanical Structure Engineer, 2017

Skills

- CAD/CAE, Manufacturing, Robotics, IOT, AR/VR, and coding (Python, Matlab, C#).
- Fluent in English, native in Mandarin and Cantonese.