Cao Muqing, Ph.D.

Singapore Citizen muqingc@andrew.cmu.edu muqing-cao
http://caomuqing.github.io/ muqing-cao

Education

2018 – 2023 **Ph.D., Nanyang Technological University** Electrical and Electronic Engineering
Thesis title: *Multi-Robot Sweep Coverage and Motion Planning*
Adviser: Prof. Xie Lihua
CGPA: 4.83/5.0.

2013 – 2017 **B.Eng. Aerospace Engineering, Nanyang Technological University**
CGPA: 4.81/5.0
Dean's List 2016

Appointments

2024 – · · · · **Postdoctoral Fellow**, Robotics Institute, Carnegie Mellon University
Supervisor: Prof. Sebastian Scherer
Leading a research project funded by the US Office of Naval Research (ONR).

2023 – 2024 **Postdoctoral Fellow**, School of Electrical and Electronic Engineering, Nanyang Technological University
Lead a research project with Delta Electronics on autonomous delivery robots in HDB.
Invented a novel robot configuration that secured a project contract with HTX Singapore.

2017 – 2023 **Research Assistant**, School of Electrical and Electronic Engineering, Nanyang Technological University
Completed two projects on autonomous drone inspection systems funded by ST Engineering, and Building and Construction Authority (BCA).

Publications

Under Review

1. **M. Cao**, K. Cao, X. Xu, S. Yuan, Y. L. Wong, and L. Xie, "Braid-based entanglement-free trajectory planning for multiple tethered robots," revised submission to *IEEE International Journal of Robotics Research*.
2. R. Jin, X. Xu, Y. Yang, J. Li, **M. Cao**, and L. Xie, "Tethered uav autonomous knotting on environmental structures for transport," submitted to *Cyborg and Bionic Systems*.
3. B. Moon, N. Suvarna, A. Jong, S. Chatterjee, J. Yuan, **M. Cao**, and S. Scherer, "Ia-tigris: An incremental and adaptive sampling-based planner for online informative path planning," revised submission to *IEEE Transactions on Robotics*.
4. J. Yuan, B. Moon, **M. Cao**†, and S. Scherer, "Hierarchical planning for long-horizon multi-target tracking under evolving uncertainty," submitted to *IEEE Robotics and Automation Letter*.

Journal Articles

1. **M. Cao***, T.-M. Nguyen*, S. Yuan, A. Anastasiou, A. Zacharia, S. Papaioannou, P. Kolios, C. G. Panayiotou, M. M. Polycarpou, X. Xu, M. Zhang, F. Gao, B. Zhou, B. M. Chen, and L. Xie, "Cooperative aerial robot inspection challenge: A benchmark for heterogeneous multi-uncrewed-aerial-vehicle planning and lessons learned," *IEEE Robotics & Automation Magazine*, pp. 2–13, 2025.
2. L. Chen, C. Liang, S. Yuan, **M. Cao**, and L. Xie, "Relative localizability and localization for multi-robot systems," *IEEE Transactions on Robotics*, pp. 1–19, 2025.
3. Y. Liao, X. Xu, R. Bai, Y. Yang, **M. Cao**, S. Yuan, and L. Xie, "Following is all you need: Robot crowd navigation using people as planners," 2025, Accepted to *IEEE Robotics and Automation Letter* 2025.
4. J. Li, S. Yuan, **M. Cao**, T.-M. Nguyen, K. Cao, and L. Xie, "Hcto: Optimality-aware lidar inertial odometry with hybrid continuous time optimization for compact wearable mapping system," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 211, pp. 228–243, 2024.
5. X. Xu, Y. Yang, **M. Cao**†, T.-M. Nguyen, K. Cao, and L. Xie, "A data-driven control method for ground locomotion on sloped terrain of a hybrid aerial-ground robot," *Journal of Automation and Intelligence*, vol. 3, no. 4, pp. 219–229, 2024.
6. Y. Yang, S. Yuan, J. Yang, T. H. Nguyen, **M. Cao**, T.-M. Nguyen, H. Wang, and L. Xie, "Av-fdti: Audio-visual fusion for drone threat identification," *Journal of Automation and Intelligence*, vol. 3, no. 3, pp. 144–151, 2024.
7. Z. Zheng, Q. Cai, J. Wang, X. Xu, **M. Cao**, H. Yu, J. Li, J. Meng, and G. Lu, "Capsulebot: A novel hybrid aerial-ground bi-copter robot with two actuated-wheel-rotors," *IEEE Robotics and Automation Letters*, 2024.
8. **M. Cao**, K. Cao, S. Yuan, T.-M. Nguyen, and L. Xie, "Neptune: Nonentangling trajectory planning for multiple tethered unmanned vehicles," *IEEE Transactions on Robotics*, 2023.
9. **M. Cao**, K. Cao, X. Li, and L. Xie, "Distributed control of multirobot sweep coverage over a region with unknown workload distribution," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 2023.
10. **M. Cao***, X. Xu*, K. Cao, and L. Xie, "System identification and control of the ground operation mode of a hybrid aerial–ground robot," *Control Theory and Technology*, pp. 1–11, 2023.
11. K. Cao*, **M. Cao***, S. Yuan, and L. Xie, "Direct: A differential dynamic programming based framework for trajectory generation," *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 2439–2446, 2022.
12. K. Cao, **M. Cao**, and L. Xie, "Similar formation control via range and odometry measurements," *IEEE Transactions on Cybernetics*, 2023.
13. Y. Lyu, **M. Cao**, S. Yuan, and L. Xie, "Vision-based plane estimation and following for building inspection with autonomous uav," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 2023.
14. Y. Lyu, T.-M. Nguyen, L. Liu, **M. Cao**, S. Yuan, T. H. Nguyen, and L. Xie, "Spins: A structure priors aided inertial navigation system," *Journal of Field Robotics*, vol. 40, no. 4, pp. 879–900, 2023.
15. K. Liu and **M. Cao**, "Dlc-slam: A robust lidar-slam system with learning-based denoising and loop closure," *IEEE/ASME Transactions on Mechatronics*, vol. 28, no. 5, pp. 2876–2884, 2023.
16. T.-M. Nguyen, S. Yuan, **M. Cao**, Y. Lyu, T. H. Nguyen, and L. Xie, "Ntu viral: A visual-inertial-ranging-lidar dataset, from an aerial vehicle viewpoint," *The International Journal of Robotics Research*, vol. 41, no. 3, pp. 270–280, 2022.
17. **M. Cao**, K. Cao, X. Li, S. Yuan, Y. Lyu, T.-M. Nguyen, and L. Xie, "Distributed multi-robot sweep coverage for a region with unknown workload distribution," *Autonomous Intelligent Systems*, vol. 1, no. 1, p. 13, 2021.

18 T.-M. Nguyen, **M. Cao**, S. Yuan, Y. Lyu, T. H. Nguyen, and L. Xie, "Viral-fusion: A visual-inertial-ranging-lidar sensor fusion approach," *IEEE Transactions on Robotics*, vol. 38, no. 2, pp. 958–977, 2021.

19 T.-M. Nguyen, S. Yuan, **M. Cao**, L. Yang, T. H. Nguyen, and L. Xie, "Miliom: Tightly coupled multi-input lidar-inertia odometry and mapping," *IEEE Robotics and Automation Letters*, vol. 6, no. 3, pp. 5573–5580, 2021.

20 T. H. Nguyen, T.-M. Nguyen, **M. Cao**, and L. Xie, "Loosely-coupled ultra-wideband-aided scale correction for monocular visual odometry," *Unmanned Systems*, vol. 8, no. 02, pp. 179–190, 2020.

21 T.-M. Nguyen, Z. Qiu, **M. Cao**, T. H. Nguyen, and L. Xie, "Single landmark distance-based navigation," *IEEE Transactions on Control Systems Technology*, vol. 28, no. 5, pp. 2021–2028, 2019.

22 T.-M. Nguyen, Z. Qiu, T. H. Nguyen, **M. Cao**, and L. Xie, "Distance-based cooperative relative localization for leader-following control of mavs," *IEEE Robotics and Automation Letters*, vol. 4, no. 4, pp. 3641–3648, 2019.

23 T.-M. Nguyen, Z. Qiu, T. H. Nguyen, **M. Cao**, and L. Xie, "Persistently excited adaptive relative localization and time-varying formation of robot swarms," *IEEE Transactions on Robotics*, vol. 36, no. 2, pp. 553–560, 2019.

Conference Proceedings

1 S. Baek*, B. Moon*, S. Kim*, **M. Cao**, C. Ho, S. Scherer, and J. h. Jeon, "Pipe planner: Pathwise information gain with map predictions for indoor robot exploration," Accepted to *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2025*.

2 **M. Cao**, X. Xu, Y. Yizhuo, L. Jianping, T. Jin, P. Wang, T.-Y. Hung, G. Lin, and L. Xie, "Learning dynamic weight adjustment for spatial-temporal trajectory planning in crowd navigation," *IEEE International Conference on Robotics and Automation*, 2025.

3 Y. Liao, **M. Cao**, X. Xu, and L. Xie, "Atom: Adaptive theory-of-mind-based human motion prediction in long-term human-robot interactions," *IEEE International Conference on Robotics and Automation*, 2025.

4 **M. Cao***, J. Zhao*, X. Xu, and L. Xie, "Aircrab: A hybrid aerial-ground manipulator with an active wheel," *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2024.

5 X. Xu, **M. Cao**, S. Yuan, T. H. Nguyen, T.-M. Nguyen, and L. Xie, "A cost-effective cooperative exploration and inspection strategy for heterogeneous aerial system," in *2024 IEEE 18th International Conference on Control & Automation (ICCA)*, 2024, pp. 673–678.

6 **M. Cao**, K. Cao, S. Yuan, K. Liu, Y. L. Wong, and L. Xie, "Path planning for multiple tethered robots using topological braids," in *Robotics: Science and Systems 2023*, 2023.

7 **M. Cao***, X. Xu*, S. Yuan, K. Cao, K. Liu, and L. Xie, "Doublebee: A hybrid aerial-ground robot with two active wheels," in *2023 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2023.

8 Y. Yang, S. Yuan, **M. Cao**, J. Yang, and L. Xie, "Av-pedaware: Self-supervised audio-visual fusion for dynamic pedestrian awareness," in *2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2023, pp. 1871–1877.

9 T.-M. Nguyen, **M. Cao**, S. Yuan, Y. Lyu, T. H. Nguyen, and L. Xie, "Liro: Tightly coupled lidar-inertia-ranging odometry," in *2021 IEEE international conference on robotics and automation (ICRA)*, IEEE, 2021, pp. 14 484–14 490.

10 **M. Cao**, Y. Lyu, S. Yuan, and L. Xie, "Online trajectory correction and tracking for facade inspection using autonomous uav," in *2020 IEEE 16th International Conference on Control & Automation (ICCA)*, IEEE, 2020, pp. 1149–1154.

11 T.-M. Nguyen, T. H. Nguyen, **M. Cao**, Z. Qiu, and L. Xie, "Integrated uwb-vision approach for autonomous docking of uavs in gps-denied environments," in *2019 International Conference on Robotics and Automation (ICRA)*, IEEE, 2019, pp. 9603–9609.

12 T. H. Nguyen, **M. Cao**, T.-M. Nguyen, and L. Xie, "Post-mission autonomous return and precision landing of uav," in *2018 15th international conference on control, automation, robotics and vision (ICARCV)*, IEEE, 2018, pp. 1747–1752.

13 T.-M. Nguyen, Z. Qiu, **M. Cao**, T. H. Nguyen, and L. Xie, "An integrated localization-navigation scheme for distance-based docking of uavs," in *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, IEEE, 2018, pp. 5245–5250.

14 H. Wang, **M. Cao**, H. Jiang, and L. Xie, "Feasible computationally efficient path planning for uav collision avoidance," in *2018 IEEE 14th International Conference on Control and Automation (ICCA)*, IEEE, 2018, pp. 576–581.

Patents

1 **M. Cao**, L. Xie, and H. Tzu-Yi, "A planning method for car-like delivery robot in human-dense environment," In preparation, 2024.

2 L. Xie, T.-M. Nguyen, **M. Cao**, and S. Yuan, "Unmanned aerial vehicle and localization method for unmanned aerial vehicle," US Patent App. 18/040,148, 2023.

* indicates equal contribution, † indicates corresponding author.

Awards

2025 **Robotics: Science and Systems (RSS) Pioneer** (33 early-career robotics researcher, 14.6% acceptance)

2023 **IEEE IROS Best Entertainment and Amusement Paper Award**

Best Presentation Award, ZheJiang University National Academic Forum for PhD Candidates.

2022 **Outstanding Presentation Award**, ZheJiang University National Academic Forum for PhD Candidates.

2017 1**st Runner-up**, Singapore Amazing Flying Machine Competition category D2 (semi-autonomous).

2016 **Dean's List Award** for achieving top 5% academic performance of the cohort.

2013-2017 NTU Science and Engineering Undergraduate Scholarship.

Teaching

Workshop *Introduction to Aerial Robotics*, seeNTU 2023, Nanyang Technological University, May 2023. Main instructor of the half-day workshop.

SAFMC Workshop D/E, Singapore Amazing Flying Machine Competition 2016, Science Centre Singapore, February 2016. Main instructor for a full-day workshop on radio-controlled drones, including theory, plane construction, and flight training.

Mentoring

2024-2025 MSc Dissertation *"Autonomous Planning of Hybrid Aerial-ground Robots in Complex Environments"*.

Mentoring (continued)

- MSc Dissertation *"Autonomous and Socially Compliant Robot Navigation for Taking a Lift"*.
- MSc Dissertation *"Inverse reinforcement learning of implicit dynamical system"*.

2023-2024
- MSc Dissertation *"Build and control a novel aerial robot with an active contact mechanism"*.
- MSc Dissertation *"Generating a vector map for robot path planning"*.
- Undergraduate Capstone *"Design and development of a small hybrid air-ground robot"*.

2022-2023
- MSc Dissertation *"Build and control a novel hybrid flying-moving robot"*. This work received the IROS Best Entertainment and Amusement Paper Award.
- MSc Dissertation *"Design and Implementation of Control Algorithms for a Tethered UAV"*.

2021-2022
- Undergraduate Capstone *"Realistic Simulation of Multiple UAVs Collaborative Inspection of Large Outdoor Structure"*. Student received grade A.

2020-2021
- Undergraduate Capstone *"Realistic Simulation of UAV Executing a Task of Inspecting Large Outdoor Structure"*. Student received grade A.

2019-2020
- Undergraduate Capstone *"Multi-Rotor Control and Autonomous Mission through Simulation"*. Student received grade B+.

2018-2019
- Undergraduate Capstone *"Target Tracking and Pursuit of Unmanned Aerial Vehicle using Radar Sensor"*. Student received grade A.
- Undergraduate Capstone *"Collision-free Path Planning of Unmanned Aerial Vehicle(UAV) using Radar Sensor"*. Student received grade A-.

Professional Services

Workshop
- Organizer, **2nd Multi-Robot Perception and Navigation Challenges in Logistics and Inspection Tasks**, IEEE/RSJ International Conference on Intelligent Robots and Systems, 2025
  Organizer, **Multi-Robot Perception and Navigation Challenges in Logistics and Inspection Tasks**, IEEE/RSJ International Conference on Intelligent Robots and Systems, 2024

Competition
- Organizer, **Cooperative Aerial Robot Inspection Challenge (CARIC)**, Conference on Decision and Control (CDC), 2023

Associate Editor
- IEEE International Conference on Control and Automation (ICCA) 2025
  IEEE International Conference on Control and Automation (ICCA) 2024
  IEEE International Conference on Control and Automation (ICCA) 2022

Session Co-chair
- Human Motion Sensing, International Conference on Robotics and Automation (ICRA), 2025
  Localization, Navigation and Mapping (II), International Conference on Control, Automation, Robotics and Vision (ICARCV), 2018

Seminars
- *Task and Motion Planning for Multi-Robot Systems in Long-duration Coverage Missions*, Singapore University of Technology and Design (SUTD), July 2024.

  Multi-Robot Sweep Coverage and Tether-Aware Planning, China University of Mining and Technology, December 2023.

  Multi-Robot Sweep Coverage and Tether-Aware Planning, Wuhan University, May 2023.

  Robot Localization in GPS-denied Environments: Past and Future, Official Launch of the Delta-NTU Corporate Laboratory for Advanced Robotics, Nanyang Technological University, June 2023.

Professional Services (continued)

Reviewer	IEEE ICRA IEEE/RSJ IROS IEEE RA-L International Journal of Robotics Research (IJRR) IEEE Transactions on Robotics IEEE Transactions on Automatic Control IEEE Transactions on Intelligent Vehicles IEEE Transactions on Industrial Electronics IEEE Transactions on Instrumentation and Measurement Science China Information Sciences International Journal of Adaptive Control and Signal Processing. IEEE Journal of Oceanic Engineering

Skills

Languages	Strong reading, writing and speaking competencies for English and Mandarin Chinese.
Coding	C/C++, python, LaTeX, …
Robotics	ROS, Eigen, Gazebo, Unity
Drones	Ardupilot, PX4, DJI SDK
Optimization	OOQP, Gurobi, Mosek

References

Prof Xie Lihua
President's Chair, Professor,
School of Electrical and Electronic Engineering,
Nanyang Technological University,
50 Nanyang Avenue.
elhxie@ntu.edu.sg

Prof Sebastian Scherer
Associate Research Professor,
Robotics Institute,
Carnegie Mellon University,
1723 Murray Avenue, Pittsburgh 15217.
basti@andrew.cmu.edu