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2024 年度 永守財団 研究助成 研究報告書

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1. 研究題目

A Unified Glocal Motion Control Framework for Multi-Motor Vehicles

2. 研究目的

Scientific purpose: This study is to propose a novel framework to design and analyze the motion control methods for multi-motor vehicles (Fig. 1) to simultaneously attain several global and local performances, and robustly operate under strict conditions, such as unknown disturbance, actuator fault, sensor delay, and the limitation of energy in long time operation.

Education purpose: This study is to develop a set of multi-motor systems for the motion control education at both undergraduate and graduate levels, to promote students' experimental skill and their understanding of advanced control theory.

学術的目的：本研究は、複数モータを搭載したビークル(図1)に対して、複数のグローバルおよびローカル性能を同時に達成し、かつ未知外乱、アクチュエータ故障、センサ遅延、長時間運用におけるエネルギー制約といった厳しい条件下でもロバストに動作可能な運動制御手法を設計・解析するための新たなフレームワークを提案することを目的とする。

教育的目的：本研究は、学部および大学院レベルの運動制御教育を対象として、学生の実験技能および先端制御理論に関する理解を深化させるためのマルチモータシステムを開発することを目的とする。

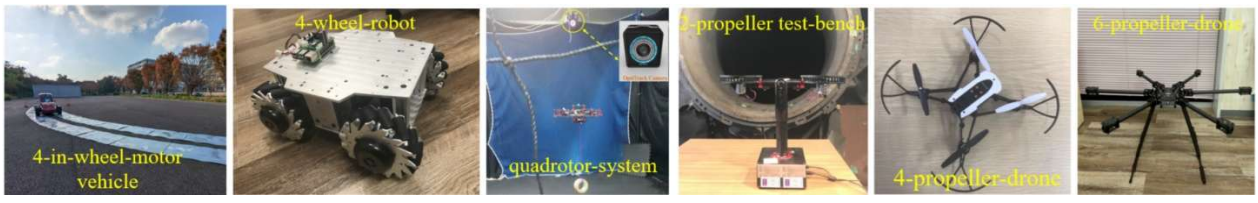

Fig. 1. Multi-motor systems studied by the grant recipient.

3. 研究内容及び成果

3.1. Research content

Problem setting: This study proposes a general motion control system as in Fig. 2. The upper-layer and lower-layer are connected via the *Aggregation* and *Distribution* channels. The upper-layer controller is provided with disturbance observer (DOB) to deal with the disturbance and

uncertainty of the vehicle body. Each local controller in the lower-layer is also provided with DOB to deal with the local disturbance and uncertainty.

Methodology:

A. Modelling: Using the idea of "shared model set," the control system in Fig. 2 will be separately represented as some standard robust control problems for the upper-layer controller and lower-layer controller. This reduces the burden of stability analysis, as the complexity of each problem does not rely on the number of motor actuators.

B. Design: Robust control theories, including μ-synthesis, are utilized to design the control system and clarify the relationship between the control performance and the shared model set.

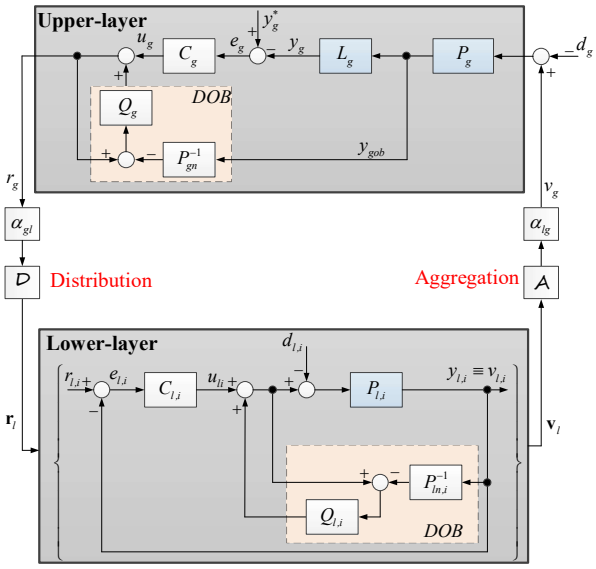

Fig. 2. Hierarchical DOB control system under study.

C. Evaluation: The method will be evaluated by both simulation and experiment. Applying the framework in Fig. 2 to flying vehicles, we have a system that controls the vehicle attitude and propeller speeds simultaneously. Applying the framework to electric vehicles, we have a system that controls the speed and wheel driving forces simultaneously.

3.2. Scientific achievement

Based on the aforementioned research philosophy, we focused deeply on driving force control of electric vehicles. A comprehensive survey on driving force control will be published at IEEJ-JIA [1]. The global-local performance analysis was presented at IEEE-IECON 2025 [2], and a study on system stability analysis was presented at IEEE-VPPC 2024 [3].

Considering the flying vehicle applications, a study on attitude control based on propeller speed control was published at IEEJ-JIA 2025 [4]. This study shows that under strong wind disturbance, the hierarchical DOB can successfully improve the yaw angle tracking performance compared to the conventional strategies.

3.3. Educational activities

Thanks to Nagamori grant, we have continuously supported the research of students at e-Mobility and Control Lab, the University of Tokyo. A student used the dual-motor testbench developed under the Nagamori-grant to conduct research on online estimation of drone body's moment of inertia [5]. A concept of active-sensing-wheel was proposed by another student for maximizing the driving force for electric vehicles [6].

Recently, our student built up a mecanum-wheel-robot driven by four motors, and a Nvidia-Jetson based multi-sensor network. The system was utilized by an internship student from Eindhoven University of Technology, to study advanced driver-assistant system (Fig. 3).

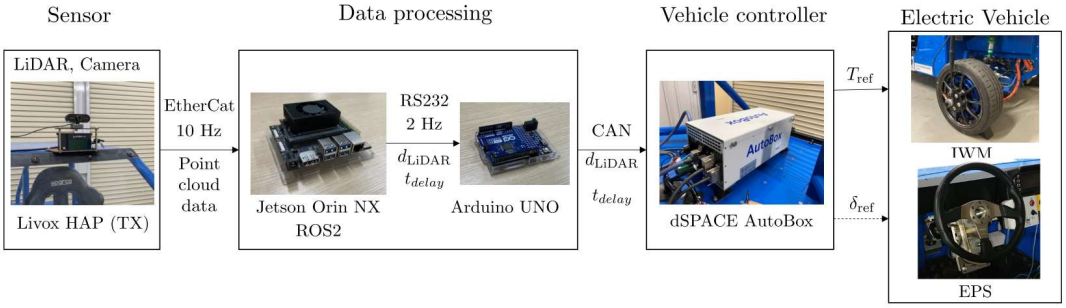

Fig. 3. Multi-sensor system based on Jetson computing board.

3.4. Joint research activities

We have worked with researchers from University of Sherbrooke to develop the simulator of a multi-motor electric vehicle, which is driven by both inductance motor and permanent magnet synchronous motor. The simulator has been used to study energy management by optimal allocation of motor torques and d-axis currents [7].

We have recently collaborated with researchers from Shanghai Jiao Tong University to develop the yaw moment control system for electric vehicle driven by several in-wheel-motors and steering-motors by utilizing reinforcement learning [8].

3.5. Society services

We have collaborated with researchers all over the world to promote research on multi-motor vehicles. In 2025, we organized/co-organized the following scientific events:

V. Ivanov, **B.-M. Nguyen**, X. Wu and K. Nam, "Multi-actuated Motion Control in the Context of Electric Vehicles," Tutorial, IEEE Vehicle Power and Propulsion Conference (2025).

V. Ivanov, **B.-M. Nguyen**, A. Tota, and H. Vansompel, "Next-Generation Powertrains for Electric Vehicles: High-Efficiency Machines, Intelligent Integration and Advanced Automated Control," Special Session, The 51st Annual Conference of the IEEE Industrial Electronics Society (2025).

B-M. Nguyen, S. Nagai, and V. Ivanov, "Advanced Control Technologies for Multi-Motor Vehicles," Special Session, IEEE International Conference on Mechatronics (2025).

B.-M. Nguyen, "Motion Control of Multi-Motor Electric Vehicles," Invited lecture, Shanghai Jiao Tong University, School of Mechanical Engineering (2025) [https://me.sjtu.edu.cn/tsfx-xsbg/77183.html]

4. 今後の研究の見通し

The theoretical results and methodologies developed under this research program can be further employed to develop motion control of electric vehicles and flying vehicles. We aim to develop other experimental systems to validate the proposal. We also utilize some results of this research program to design motion control systems for electric dump trucks and underwater electric vehicles.

5. 助成研究による主な発表論文，著書名

[1] **B.-M. Nguyen**, Y. Hosomi, Y. Morimoto, T. Mizuguchi, and H. Fujimoto, "A Comprehensive History of Driving Force Control for Electric Vehicles," IEEE Journal of Industry Applications (to be published, 2026).

[2] **B.-M. Nguyen**, A. Tota, H. Fujimoto, A. Sorniotti, and S. Hara, "Global/Local Performance Analysis of Driving Force Based Hierarchical Decentralized Motion Control System for Multi-motor Vehicles," The 51st Annual Conference of the IEEE Industrial Electronics Society (2025).

[3] **B.-M. Nguyen**, T. Ueno, Y. Hosomi, T. Sato, S. Hara, and H. Fujimoto, "Wheel Speed based Driving Force Control for Multi-motor Vehicles with Glocal Stability Analysis using Generalized Frequency Variable," IEEE Vehicle Power and Propulsion Conference (2024).

[4] **B.-M. Nguyen**, S. Hara, and H. Fujimoto, "Disturbance Observer-Based Global/Local Control Using Shared Model Set: Design Concept with Practical Application to Multi-rotors," IEEJ Journal of Industry Applications, Vol. 14, No. 3, pp. 431-441, doi: 10.1541/ieejjia.24006733 (2025).

[5] 廣田万由子，神谷万人，猶木雄登，藤本浩太，横田健太朗，**阮平明**，永井栄寿，清水修，藤本博志，"マルチロータ機における反トルクオブザーバを用いた z 軸周りの慣性モーメント推定法の基礎研究"，電気学会メカトロニクス制御研究会 2025，東京，pp.37-42, 2025.

[6] Y. Morimoto, T. Mizuguchi, Y. Hosomi, **B.-M. Nguyen**, H. Fujimoto: "Proposal of Active Sensing Wheel Based Optimal Slip Ratio Estimation for In-Wheel Motor Vehicles," The 10th IFAC Symposium on Mechatronic Systems (2025).

[7] A.-T. Nguyen, **B.-M. Nguyen**, J. P. F. Trovao, and M. C. Ta, "Comprehensive Modelling of Electric Vehicles for Multi-Objective Control Design," IEEE Open Journal of Vehicular Technology Vol. 6, pp. 2479-2493 (2025).

[8] S. Zhao, **B.-M. Nguyen**, H. Lu, R. Yu, R. Yu, and X. Wu, "Reinforcement Learning-based Coordinated Control Arbitration for Vehicle Yaw Motion with Parameter Activated Torque Distribution," Control Engineering Practice, Vol. 166, No. 106618 (2025).