Research Statement

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1. Vision: Intelligent Aerial Manipulation

Aerial robots can perform dexterous tasks in diverse environments due to their exceptionally high maneuverability compared to human workers and ground robots. This capability enables them to perform robotic manipulation in hazardous locations—such as high-altitude or contaminated areas, including wind turbines, transmission towers, the interiors of nuclear power plants, and disaster zones. **Carrying out tasks involving physical interaction with aerial manipulators — that is, aerial robots equipped with robotic arms — can enhance economic efficiency and significantly reduce the risk of human damages.** In this context, my ultimate goal is the full replacement of human workers in dangerous environments with **intelligent aerial manipulators**. However, it is widely acknowledged within the aerial robotics community that **fully autonomous aerial manipulation (similar to Level 5 of autonomous driving system) has not yet been achieved**.

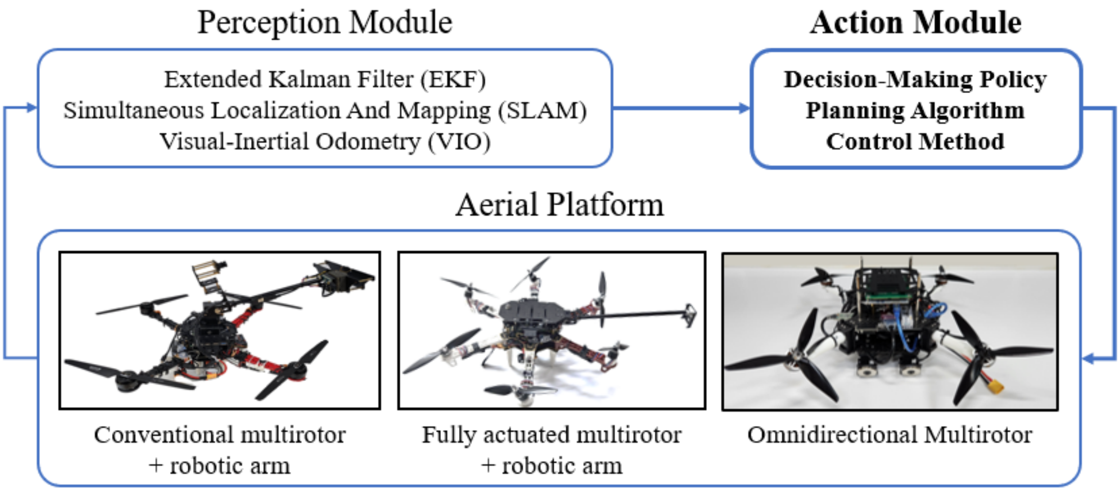

Figure 1 Structure of intelligent aerial manipulation

As shown in Figure 1, an aerial manipulation system typically consists of three components: an action module, a perception module, and an aerial platform. In the direction of fostering mutual and positive feedback among these three modules, my research primarily focuses on the development of the **action module**, which enables aerial robots to autonomously determine **what to do (decision-making policy)**, **where and when to go (planning algorithm)**, and **how to go (control method)**. All these elements are developed to guarantee the aerial manipulator's stability, safety, and operational efficiency comparable to — or even surpassing — that of human workers, **supported by theoretical proofs and experimental validations**. I believe that this modular approach provides rigorous theoretical guarantees for reliable aerial manipulation and enables a module-by-module debugging when issues arise.

2. Past Works: Provably Stable Low-Level Controllers

My past works can be arranged as follows:

Hybrid Control: In [1], I designed a hybrid controller for extracting a wedged object (e.g., plug-pulling), with a focus on enhancing transient performance after the extraction. The performance improvement and system stability were analytically derived and experimentally validated through both mathematical analysis and hardware experiments.

Safety-Critical Control: In [2, 3], I designed a safety-critical controller that guarantees motor thrust constraints and ensures disturbance attenuation performance with provable collision avoidance. This control scheme was validated through pushing and pulling experiments involving both static and dynamic structures, as well as object-picking experiments conducted in cluttered environments.

Switched Motion/Force Control for Stable Contact: Based on my previous works on motion/force control of an aerial manipulator [4, 5], I designed a motion/force controller that explicitly models static friction and adjusts motion/force profiles to maintain bounded contact force errors and prevent actuator saturation. **(Conducted with support from the Brain Korea 21 (BK21) Ph.D. Fellowship and recognized with an Honorable Mention in the Aerospace Paper Award presented by Korean Aerospace Industries (KAI), Ltd.)**

3. Ongoing and Future Works: Summing Up Controller and Moving Towards High-Level Planners and Decision-Making Policies with Multiple Agents

My ongoing and future objectives are centered in summing up my control frameworks to an integrated form and moving towards high-level planners and decision-making policies with multiple agents. This includes:

<u>Versatile hybrid controller with guaranteed stability, safety and reliability</u>: Building upon my previous publications, I am designing a controller applicable to a wide range of aerial manipulation tasks, while simultaneously ensuring flight stability under discontinuous external disturbances, motor thrust limitations, system passivity, and compliant robot–environment interaction.

<u>Cooperative Aerial Manipulation</u>: Building upon theorems and control frameworks designed for a single aerial manipulator, I aim to propose control and planning methods for multiple aerial manipulators in a decentralized manner. Unlike the single-agent case, I aim to resolve issues related to (i) minimization of internal interaction forces between agents, (ii) conflict in distributed multi-agent planning, (iii) heterogeneous agents, and (iv) other challenges.

<u>Frameworks for data acquisition and imitation learning-based decision-making policy</u>:

1) **High-fidelity simulator of aerial physical interaction:** I am currently building simulators leveraging commercial physics engines (e.g., Isaac sim) that accurately replicate the dynamic behavior of aerial manipulators physically interacting with surrounding

environments.

2) **Visual-haptic bilateral teleoperation framework**: Following my preliminary work on haptic-based shared control of an aerial manipulator extracting a wedged object [6], I am designing a visual-haptic bilateral teleoperation framework for aerial manipulation to gather real-world data for imitation learning.

Leveraging data acquired from high-fidelity simulators and skilled human experts, I ultimately aim to obtain a decision-making policy for aerial manipulators. This policy includes situation awareness based on visual information (serving the role of human vision), reasoning behind the interpretation, and task selection accordingly.

References

[1] J. Byun, I. Jang, D. Lee, and H. J. Kim, "A hybrid controller enhancing transient performance for an aerial manipulator extracting a wedged object," IEEE Transactions on Automation Science and Engineering, vol. 21, no. 3, pp. 3264–3273, 2023.

[2] J. Byun, Y. Kim, D. Lee, and H. J. Kim, "Safety-critical control for aerial physical interaction in uncertain environment," in 2025 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2025, pp. 7526–7532.

[3] L. Yang, J. Lee, D. Campolo, H. J. Kim, and J. Byun, "Whole-body motion planning and safety-critical control for aerial manipulation," in arxiv preprint, arXiv:2511.02342 [cs.RO]

[4] J. Byun, J. Kim, D. Eom, D. Lee, C. Kim, and H. J. Kim, "Image-based time-varying contact force control of aerial manipulator using robust impedance filter," IEEE Robotics and Automation Letters, 2024.

[5] J. Byun, B. Kim, C. Kim, D. D. Oh, and H. J. Kim, "Stable contact guaranteeing motion/force control for an aerial manipulator on an arbitrarily tilted surface," in 2023 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2023, pp. 5345–5351.

[6] J. Byun, D. Eom, and H. J. Kim, "Haptic-based bilateral teleoperation of aerial manipulator for extracting wedged object with compensation of human reaction time," in 2024 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE, 2024, pp. 624–630.