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Demo Abstract: Bio-inspired Tactile Sensing for MAV Landing with Extreme Low-cost Sensors

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ABSTRACT

MAV (Micro Aerial Vehicle) requires landing on a docking platform for recharging during or after missions due to their limited energy capacity. Inspired by biological tactile sensing, we propose a proprioceptive sensing system that allows MAV to "touch", recognize, and locate the landing platform even when visual or other positioning systems are not functioning properly. We leverage a physical phenomenon: as the MAV approaches a beneath obstacle, it experiences attitude disturbances caused by the airflow generated by the rotor's reflections from the ground. By employing traditional signal processing and learning-based techniques to analyze signals from the IMU (Inertial Measurement Unit) and motors, the MAV can sense the edges of the platform and further calculate the precise landing coordinates. With a power consumption of less than 40 mW, our system achieves an edge detection error of less than 2 cm and a landing success rate exceeding 90%.

CCS CONCEPTS

• **Applied computing** → **Aerospace**; • **Computing methodologies** → **Machine learning approaches**; • **Computer systems organization** → **Sensors and actuators**.

KEYWORDS

Micro Aerial Vehicle, Ground Effect, Landing, Low-cost Sensing

1 INTRODUCTION

With the rise of satellite communication and 5G networks, Micro Aerial Vehicles (MAVs) can now perform accurate and real-time remote control and autonomous flights, enabling new applications including, surveillance[1], delivery, and disaster relief. MAVs, known for their low cost, small size, and agility, excel in these tasks, especially in collaborative or collision-prone scenarios[2]. However, their lightweight design limits the carrying capacity for high-precision sensors and large batteries[3], challenging their use in fully autonomous long-duration flights. To address this, automatic charging after landing on self-collection stations has emerged as a viable solution.

The MAV collection process involves the vehicle approaching a designated landing platform and executing a carefully planned landing procedure. Different techniques, including GNSS (Global Navigation Satellite System), UWB (Ultra-Wideband), acoustics, and vision-based methods, have been employed to accurately locate and facilitate the landing of MAVs onto the platform[4][5]. However, implementing these methods requires additional infrastructure and sensors on the MAV, which can increase weight and reduce operational efficiency during a single trip.

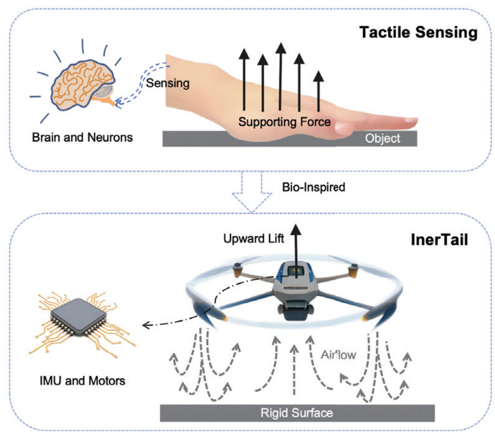

Figure 1: The MAV "touches" the rigid platform surface using emitted airflow from the rotors, and the tactile sensing message is captured by IMU and motor signals from MAV body, similar to how tactile sensing works for humans.

To address these challenges, we propose AttitudeTouch, a proprioceptive sensing system that utilizes attitude information, IMU sensors, and motor signals available on a typical MAV, along with the ground effect phenomenon[6], to locate and land the MAV on the platform without additional sensors. Our detection system is inspired by bio-inspired tactile sensing, as is shown in Figure 1. This system aims to address challenges of the utilizing the minor and dynamic sensing information, considering the limitation of power and computational resources of MAVs. The main contributions of this paper are as follows:

- Propose AttitudeTouch, a proprioceptive sensing system for MAV to land on the station platform only with IMU and motor signals, inspired by tactile sensing.
- Design a hierarchical framework to save power and computation resources by applying compatible detection methods.
- Evaluate the AttitudeTouch system using real world data in offline and onboard real-time implementation on an MAV.

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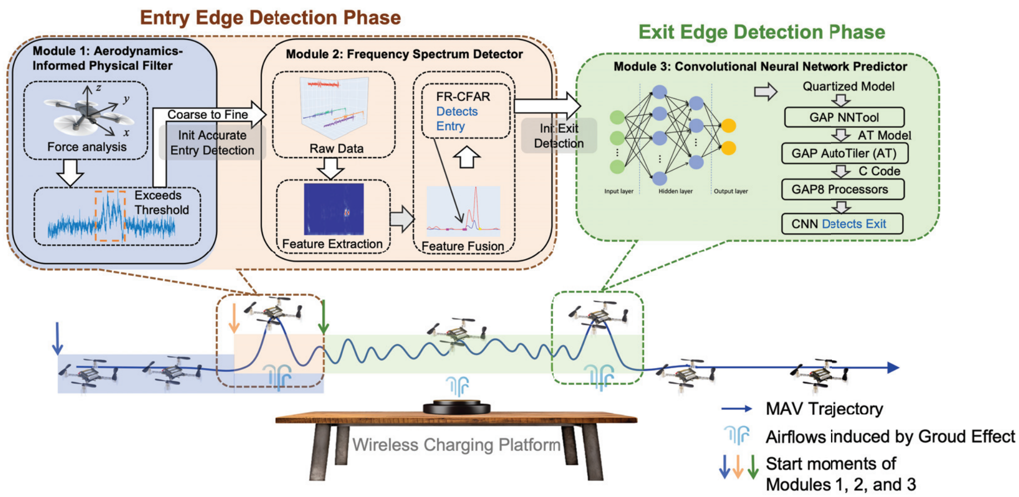

Figure 2: System and Modules

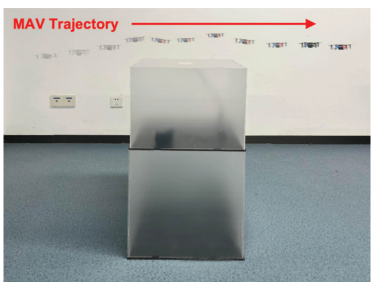

Figure 3: Flight Trajectory

2 SYSTEM DESIGN

To enhance the MAV's ability to detect the platform's edges with resource concerns, we employ a coarse-to-fine and hierarchical framework that can adjust different landing procedures. The framework consists of three core modules that cater to two crucial phases of the landing process. The first module is *Aerodynamics-Informed Physical Filter* that provides coarse sensing of the platform and is the most power- and computation-saving[7]. The second module, *Frequency Spectrum Detector*, based on frequency spectrum analysis, consumes more resources and detects the exact entry moment. The third module, *Convolutional Neural Network Predictor*, detects the exact exit moment with the highest power and computation consumption. This hierarchical design ensures real-time performance while conserving resources by self-adjustment. As shown in Figure 2, the first module and the second module are deployed to detect the entry moment of the platform, while the third module is designed for the exit moment detection.

3 DEMO

To validate our proposed architecture for MAV precise landing, we conducted experiments using the Crazyflie 2.1 nano-quadrotor developed by Bitcraze. This MAV consists of a 250mAh LiPo battery, an AI deck with a GAP8 microcontroller for model inference, and a Flow deck for optical motion detection.

We evaluate the AttitudeTouch in two ways: analyzing real-world MAV flight data offline and implementing the system onto the MAV onboard chip. Across 30 offline test groups, we calculated entry and exit errors by comparing detected and actual moments. The mean error in all 30 sets is under 100 ms, equivalent to less than 2 cm error at a forward velocity of 20 cm/s.

During the demo, we align the Crazyflie horizontally above the platform by utilizing our system to detect the four edges. Then MAV calculates the platform's center and descends vertically. The successful landing rate within a target range is almost 90%. The maximum power consumed by our system is less than 40 mW.

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