TAICHAN: Task-Aware Hierarchical Search Planning for Object-Oriented UAV Exploration in Unknown 3D Environments

Muhammad Wicaksono, Soo Young Shin*
Department of IT Convergence Engineering,
Kumoh National Institute of Technology (KIT), Gumi, South Korea
Email: {muhammadwicak97, *wdragon}@kumoh.ac.kr

Abstract

This paper presents Task-Aware Hierarchical Search Planning (TAICHAN), a hierarchical framework for UAV exploration and object-driven search in unknown 3D environments. Unlike frontier-based methods that treat all unknown space equally, TAICHAN integrates neural object estimation into the exploration pipeline to prioritize task-relevant targets. A Kalman filter maintains robust target tracking, while a mode selector switches between global coverage and target-centric sampling. Planning is decomposed into a global search tour and kinodynamic trajectory optimization, enabling smooth, collision-free navigation under real-time constraints. Simulations in cluttered scenes show improved task-oriented exploration compared with geometric frontier baselines while preserving dynamically feasible motion.

Keywords : UAV exploration, task-aware planning, semantic exploration, hierarchical planning

I. Introduction

Autonomous exploration using Unmanned Aerial Vehicles (UAVs) has become a pivotal area of research, driven by the need for rapid mapping in search-and-rescue, environmental monitoring, and industrial inspection. The primary goal of drone exploration is to autonomously navigate through unknown, cluttered environments to build a comprehensive map while avoiding obstacles. State-of-the-art frameworks, most notably FUEL (Fast UAV Exploration) by Zhou et al. [1]. However, a major limitation of these purely geometric approaches is their lack of task-awareness; they treat every cubic meter of unknown space with equal importance, often resulting in inefficient paths when the mission objective involves identifying or interacting with specific targets. To overcome these limitations, recent advancements have integrated Deep Learning-based perception into the navigation stack to enable "task-aware" exploration. By employing a Neural Network (NN) for real-time object detection and semantic segmentation,. In [2] the semantic-aware active perception using semantic cues allows a drone to prioritize regions that are perceptually more informative for a specific mission. In our proposed system, this neural-based perception is coupled with a Kalman Filter to provide robust state

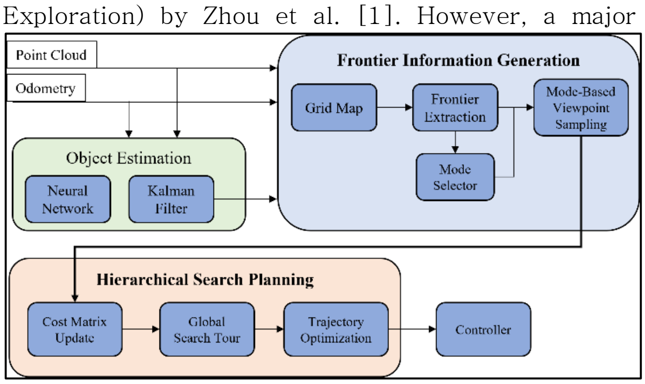

Fig. 1 Generic overview of collaborative SLAM architecture.

estimation and tracking of detected objects, even under sensor noise or temporary occlusions

Ⅱ. Proposed System

The pipeline takes raw Point Cloud and Odometry data as input as shown in Fig.1. The Neural Network processes visual/spatial data to detect objects, while the Kalman Filter tracks their position and velocity. This ensures that even if a target is momentarily occluded by obstacles, the system maintains a probabilistic estimate of its location. The environment is maintained in a Grid Map. Frontier Extraction identifies boundaries between explored and unknown space. A key innovation is the Mode Selector, which dictates the behavior of the Viewpoint Sampling module. If a target is detected, the system switches from "Exploration Mode" to "Target Mission Mode," sampling viewpoints that optimize sensor coverage of the object rather than just volume. The planning is split into a Global Search Tour and Trajectory Optimization. The global tour uses a updated Cost Matrix to solve the high-level routing problem (determining which frontier to visit first). The output is then passed to a trajectory optimizer that generates a smooth, collision-free path that respects the UAV's kinodynamic limits.

Ⅲ. Simulation

The system was evaluated in a cluttered 3D environment in Fig. 2. The simulation shows the UAV navigating a complex field of occupancy voxels. The Global Path successfully identifies a sequence of frontiers that minimize the total travel distance while maximizing information gain. The Local Trajectory demonstrates the effectiveness of the hierarchical approach, providing a smooth, high-speed path through narrow passages that the global plan alone could not provide. The integration of the Neural Network allowed the UAV to prioritize "informative frontiers" near detected objects. During the simulation, the Mode Selector successfully shifted the UAV's focus when a target was identified, ensuring that the final map contains high-resolution data for the objects of interest, rather than just empty space.

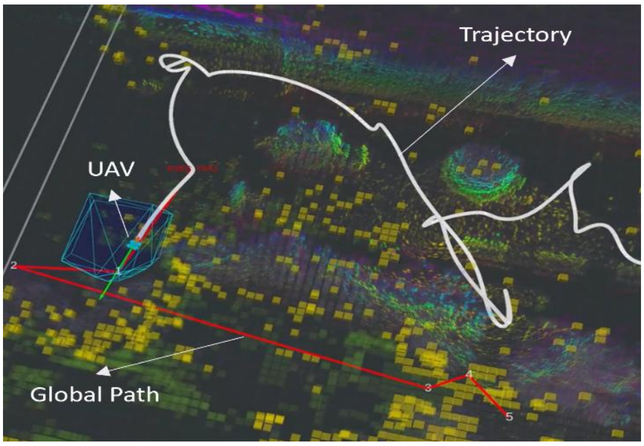

Fig. 2 UAV exploration in cluttered environment

IV. Conclusion

This paper introduced a task-aware autonomous exploration framework for UAVs. By integrating Neural Network-based perception and a Kalman Filter with a Hierarchical Search Planner. Simulation results confirm that the proposed hierarchical architecture effectively manages the complexity of cluttered 3D environments, producing smooth, kinodynamically feasible trajectories. Future work will involve integrating this system with multi-agent coordination to further increase search-and-rescue efficiency in larger-scale GPS-denied environments.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (RS-2025-00553810, 50%) This work was supported by Innovative Human Resource Development for Local Intellectualization program through the Institute of Information & Communications Technology Planning & Evaluation(IITP) grant funded by the Korea government(MSIT) (IITP-2025-RS-2020-II201612, 50%)

References

[1] B. Zhou, et al., "FUEL: Fast UAV Exploration Using Incremental Frontier Structure and Hierarchical Planning," *IEEE RA-L*, 2021.

[2] L. Bartolomei, et al., "Semantic-aware Active Perception for UAVs using Deep Reinforcement Learning," *ICRA*, 2021.