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CS 4610
Spring 2025

UAV Autonomous Navigation in Indoor and GPS-Denied Environments: Literature Review

1st Paper: Overview

Damian summary

In GPS-denied environments, UAV technology has relied on onboard sensors and various technologies such as SLAM to address this issue. While SLAM provides a solution for tracking the UAV's position while mapping the surrounding environment, it doesn't address the simultaneous and autonomous control of the UAV. Such autonomous control has been difficult to achieve while maintaining the localization and mapping functionality of SLAM. This is caused by factors such as the SLAM system's ability to handle sensor noise and uncertainties in the environment mapping. If errors occur in obtained estimates, they are prone to propagating into control algorithms. This can, in turn, cause instability, collisions, and poor trajectory adherence.[1] Another aspect of the SLAM system to consider is its high computational intensity, which might cause delays in delivering estimates to other subsystems.[1]

The term SCLAM (Simultaneous Control, Localization, and Mapping) refers to techniques for "concurrently integrating control tasks with localization and mapping tasks"." 1 The paper analyzed in this work aims to address a novel vision-based approach to SCLAM designed for UAV operation in GPS-denied environments. The paper addresses challenges such as real-time processing, autonomous exploration, home return, and the closing-the-loop problem.

ChatGPT summary

Visual-based SLAM (Simultaneous Localization and Mapping) has become a key alternative to GPS for UAV navigation in challenging environments. Using onboard cameras and computer vision, SLAM enables drones to map their surroundings and estimate their position without GPS. This technology has proven useful in applications like autonomous navigation and infrastructure inspection. However, integrating SLAM with UAV control systems in real-time remains challenging due to sensor noise, environmental dynamics, and computational demands. Errors in SLAM estimates can affect trajectory tracking and obstacle avoidance, while processing delays can reduce system responsiveness in fast-changing environments.[1]

SCLAM (Simultaneous Control, Localization, and Mapping) is introduced as the challenge of integrating UAV control with localization and mapping in real time. While SCLAM has also been used to mean Simultaneous Calibration, Localization, and Mapping, it refers to the coordination of navigation and control in GPS-denied environments. Successfully implementing SCLAM requires innovative solutions to handle the complexities of autonomous UAV operation under constrained conditions. SCLAM, used in the field of UAV control in GPS-denied environments aims to address challenges such as real-time processing, autonomous exploration, home return, and loop closure.[1]

1st Paper: Conclusions on Future Work

Future work could explore various control, estimation, and trajectory generation techniques for implementing the subsystems within the proposed architecture. This could include the use of alternative control algorithms to enable spiral or circular movements, as well as control methods that produce faster or more aggressive movement responses. While virtual experiments offer valuable insights into the potential performance of the SCLAM system in real-world scenarios, future efforts should also aim to extend these experiments to actual environments, similar to the approach taken with the SLAM subsystem in the author’s previous work.[1]

2nd Paper: Overview

The purpose of this paper is to propose a deep learning-based countermeasure strategy for unmanned aerial vehicles (UAVs) that addresses the challenges of GPS signal loss during navigation. Specifically, it introduces a return-to-home (RTH) approach that enables UAVs to autonomously return to their launch location by leveraging data from onboard sensors (e.g., accelerometer, barometer, GPS, gyroscope, magnetometer). The paper emphasizes the use of bidirectional long short-term memory (B-LSTM) modeling to process sequential data and predict/reverse flight paths.

This approach is distinct from prior solutions because it:

1. Avoids additional hardware, cooperative communication, and backup radio links.
2. Functions independently of weather or light conditions.
3. Requires lower computational resources compared to visual sensor-based methods.
4. Utilizes real-world experimental datasets instead of simulation setups, ensuring realistic model development.

The paper outlines the experimental feature extraction process, evaluates the B-LSTM models, and demonstrates the viability of the proposed RTH solution.[2]

2nd Paper: Future Work

The conclusion highlights the effectiveness of the proposed B-LSTM-based approach for return-to-home (RTH) navigation in GPS-denied scenarios. The solution accurately predicts flight paths using onboard sensor data, achieving low mean squared errors (MSE) with minimal memory and computational requirements. The approach is scalable and does not require additional hardware, making it an attractive option for autonomous aerial vehicles.

Proposed Improvements and Future Work:

1. Integration with Reinforcement Learning: Developing a hybrid navigation mechanism by combining LSTM with reinforcement learning to handle dynamic and mission-critical scenarios. This will enhance robustness, especially in environments with potential threats such as physical obstacles or cyberattacks during RTH flight paths.
2. Optimization of Model Performance: Investigating the trade-offs between accuracy, energy efficiency, and memory usage in AI-based models. Future research could explore optimization techniques for real-time energy consumption and performance across different conditions, dataset sizes, and preprocessing methods.
3. Extension to Other Autonomous Vehicles: Adapting the proposed RTH solution for ground vehicles and other autonomous systems. This could have significant implications

for the transportation industry, traffic management, and enhancing safety and accessibility.

These future directions aim to improve the robustness, adaptability, and efficiency of the proposed solution while expanding its applicability across broader domains.[2]

3rd Paper: Overview

GNSS-independent localization is one of the most prominent research problems in aerial autonomous systems navigation, especially in certain applications where Simultaneous Localization and Mapping (SLAM) methods are inapplicable due to the complexity of the environment, or in open-air spaces where a flock of Unmanned Aerial Vehicles (UAVs) navigate in a GNSS-independent fashion. This paper introduces a filter through which UAVs form a multi-agent Cellular Vehicle-to-Everything (C-V2X) network to exchange their estimated positions, and eventually achieve a group consensus over the true position of each vehicle. The localization error correction takes place in the filter with reference to the UAV's relative range from neighbouring vehicles, that is measured by onboard ranging devices. It is shown that in ideal situations where rangefinder errors can be neglected, cooperative localization yields perfect localization, if the network is sufficiently large and sufficiently connected. It is also shown that the accuracy of cooperative localization is superior to the existing least-mean-square-error based techniques, where a centralized controller augments the positioning accuracy of the flock. Cooperative localization is also favourable due to the fact that the process is computationally affordable and fully distributed. Theoretical derivations and results have been validated through case studies and Monte Carlo simulations, and suggest cooperative localization as a complementary navigation technique to odometery, and other advanced solutions that are available in the literature.

Before reading this article: read on current techniques such as odometry and SLAM in multi-UAV problems

Sources

[1]Munguia, Rodrigo, et al. "A Simultaneous Control, Localization, and Mapping System for UAVs in GPS-Denied Environments." *Drones*, vol. 9, no. 69, 2025, https://doi.org/10.3390/drones9010069.

[2]Alkhatib, Mustafa, et al. "A Return-to-Home Unmanned Aerial Vehicle Navigation Solution in Global Positioning System Denied Environments via Bidirectional Long Short-Term Memory Reverse Flightpath Prediction." *Engineering Applications of Artificial Intelligence*, vol. 125, 2024, p. 109729, https://doi.org/10.1016/j.engappai.2024.109729.

[3]Shahkar, S. “Cooperative Localization of Multi-Agent Unmanned Aerial Vehicle (UAV) Networks in Intelligent Transportation Systems” *Department of Electrical and Computer Engineering Concordia University, Montreal, Canada*
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