University of Science and Technology
Houari Boumediene

Faculty of Computer Science

How Drones See: Visual Navigation in GPS-Denied Environments

Presented by:

Tolba Adel

Timount Adnane

Kaci Aissa Maissa

Boumala Rami Amine

November 1st, 2025

Contents

1 Introduction

This report examines drone visual navigation in GPS-denied environments and explores how game theory can address the challenges associated with this problem.

2 What is a Drone?

A **drone** (also called an Unmanned Aerial Vehicle or UAV) is an aircraft that operates without a human pilot on board. It can be:

- **Remotely controlled** by a human operator
- **Autonomous** - following pre-programmed flight paths
- **Semi-autonomous** - combining both approaches

Drones use various sensors (GPS, cameras, IMUs, lidar) to navigate and perform tasks such as delivery, surveillance, mapping, search and rescue, and much more.

3 Visual Navigation in GPS-Denied Environments

3.1 The Problem

Traditional drones rely heavily on GPS for positioning and navigation. However, GPS can be **unavailable or unreliable** in:

- Indoor environments (buildings, warehouses, mines)
- Urban canyons with tall buildings
- Dense forests
- Underground locations
- Scenarios with GPS jamming or interference

3.2 Visual Navigation Solution

When GPS fails, drones must navigate using **computer vision** - essentially "seeing" like humans do. Key techniques include:

3.2.1 Visual Odometry (VO)

Tracking motion by analyzing sequential camera images to estimate the drone's trajectory.

3.2.2 Simultaneous Localization and Mapping (SLAM)

Building a map of the unknown environment while simultaneously tracking the drone's location within that map.

3.2.3 Feature Detection and Matching

Identifying distinctive visual landmarks (corners, edges, textures) and tracking them across frames.

3.2.4 Optical Flow

Analyzing the pattern of apparent motion of objects in visual scenes to understand movement.

3.2.5 Deep Learning Approaches

Neural networks trained to recognize places, estimate depth, and predict safe navigation paths.

The drone essentially creates a mental model of its surroundings using cameras and maintains position awareness through visual reference points.

4 How Game Theory Solves This Problem

Game theory can address visual navigation challenges by modeling the drone's decision-making as strategic interactions:

4.1 Adversarial Robustness

Treating environmental uncertainties as an "opponent" playing against the drone:

- Worst-case scenario planning (minimax strategies)
- Handling sensor failures or visual ambiguities
- Robust path planning against unpredictable obstacles

4.2 Resource Optimization

Balancing competing objectives:

- Battery life vs. exploration completeness (Pareto optimality)
- Computation vs. navigation accuracy trade-offs
- Risk vs. reward in path selection

4.3 Decision-Making Under Uncertainty

Using Bayesian games to handle:

- Incomplete information about the environment
- Probabilistic obstacle detection
- Uncertain visual feature reliability

5 Presenting This as a Game Theory Problem

5.1 Framework: The Visual Navigation Game

5.1.1 Players

- The Drone (decision-maker)
- The Environment (nature/adversary)
- Other Drones (in multi-agent scenarios)

5.1.2 Strategies

- *Drone strategies*: Possible flight paths, sensor fusion methods, exploration vs. exploitation choices
- *Environment strategies*: Obstacle configurations, lighting conditions, visual ambiguities

5.1.3 Payoff Function

The drone's payoff function can be expressed as:

$$U(\text{drone}) = w_1(\text{mission\_success}) - w_2(\text{energy\_consumed}) - w_3(\text{collision\_risk}) + w_4(\text{map\_quality}) \tag{1}$$

where w_1, w_2, w_3, w_4 are weights that reflect the relative importance of each component.

6 Conclusion

This game-theoretic perspective transforms visual navigation from a simple perception problem into a **strategic decision-making problem** where the drone must reason about uncertainty, optimize resources, and coordinate with others.

The combination of computer vision and game theory offers a powerful framework for developing robust and efficient autonomous navigation systems in environments where GPS is unavailable or unreliable.