Multi-sensory Anti-collision Design for Autonomous Nano-swarm Exploration

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Abstract

This work presents a robust design for swarm of palm-size nanodrones enabling autonomous exploration via obstacle avoidance, intra-swarm anti-collision and vision-based target detection capabilities fully aboard a highly resource-constrained robotic platform at less than 1W power budget. We combine lightweight single-beam laser ranging to avoid proximity collisions with a long-range vision-based obstacle avoidance deep learning model (i.e., PULP-Dronet) and an ultra-wide-band (UWB) based ranging module to prevent intra-swarm collisions.

Nanodrone Challenges

- Standard sized
  - Size [Ø, weight]
    - ≤5cm / ≤few Kg
  - Tot. Power
    - ≤100 W
  - Processing device
    - High-end CPU
  - Cognitive Capacity
    - Fully autonomous

- Next gen: nano/pico sized
  - Size [Ø, weight]
    - ≤few cm / ≤few g
  - Tot. Power
    - ≤SW
  - Processing device
    - Low-power MCU

- Laser-based obstacle avoidance
  - Fast but ineffective in cluttered environments
  - Vision-based obstacle detection
  - Effective but slow high comparison

- Need for a highly efficient and compact design suitable for nanodrone swarm [Architectures & Algorithms]

System Design

- UWB-based anchorless localization enables swarm agents to coordinate each other relatively and avoid colliding with each other during exploration

- Obstacle Detection
  - Categories
  - Bonding boxes
  - Confidence scores

- Intra-Swarm Collision Avoidance (ISCA)
  - 3D
  - Dronet

- Obstacle Collision Avoidance (OCA)
  - Distance Measures
  - PULP-Dronet [1]

- Exploration Policy
  - Finite State Machine

- Flight Control

RISC-V Dual-CNN architecture at 250kB Memory is a precise embedding of two deep-learning base algorithms handling obstacle detection and object detection in an interlinking process.

Sensor fusion and exploration policy continuously monitor sensing inputs and react accordingly based on the sensor-fusion algorithm.

Results

- Multi-modal sensing achieves 60%-70% boost in obstacle avoidance w.r.t the baseline i.e. SniffyBug [2]

- PULP-Dronet delivers optimal obstacles detection at 8 frame/second where ~82% collisions are detected.

- Multi-sensory system performs at >1W power budget

- Intra-swarm anti-collision unit achieves 92.8% accuracy

- Dual-CNN design operates at 250kB memory & 133mW power where GAP8 processor executes at 1.6FPS

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References