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

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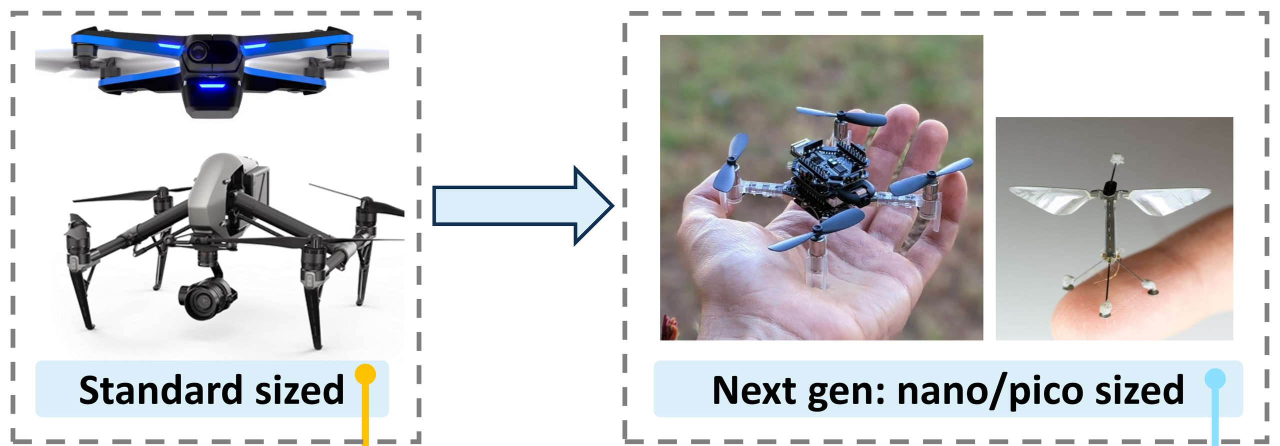
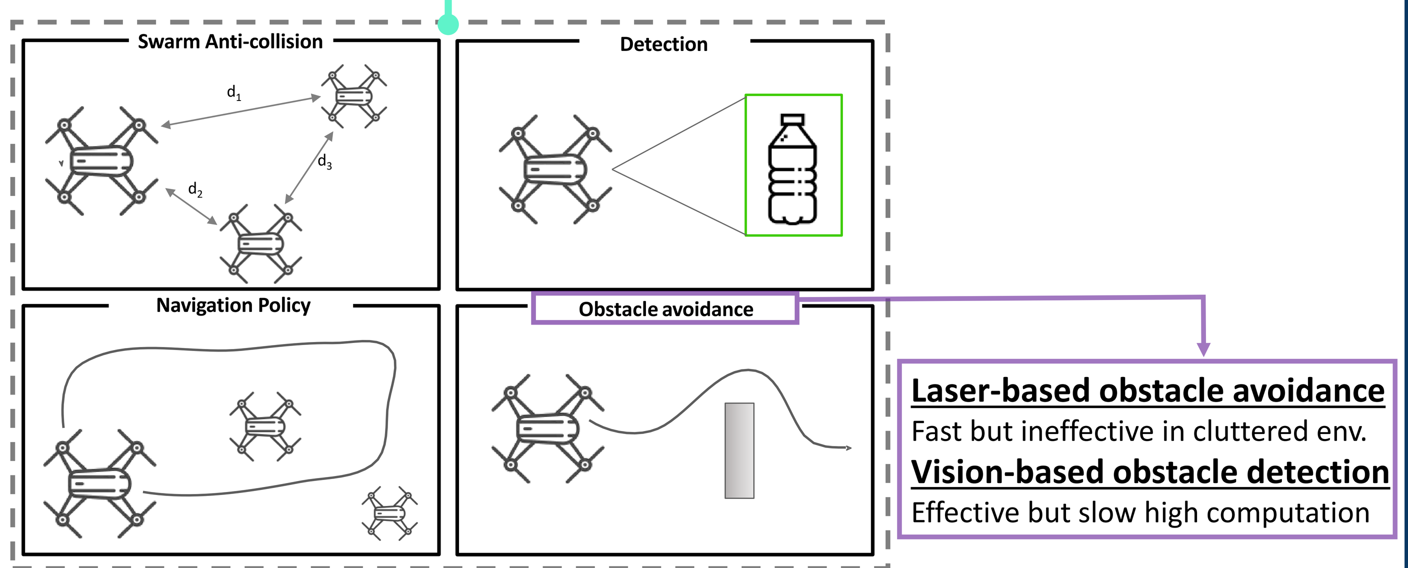
Abstract

This work presents **a robust design for swarm of palm-size nano-drones** 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.

Nano-drone Challenges



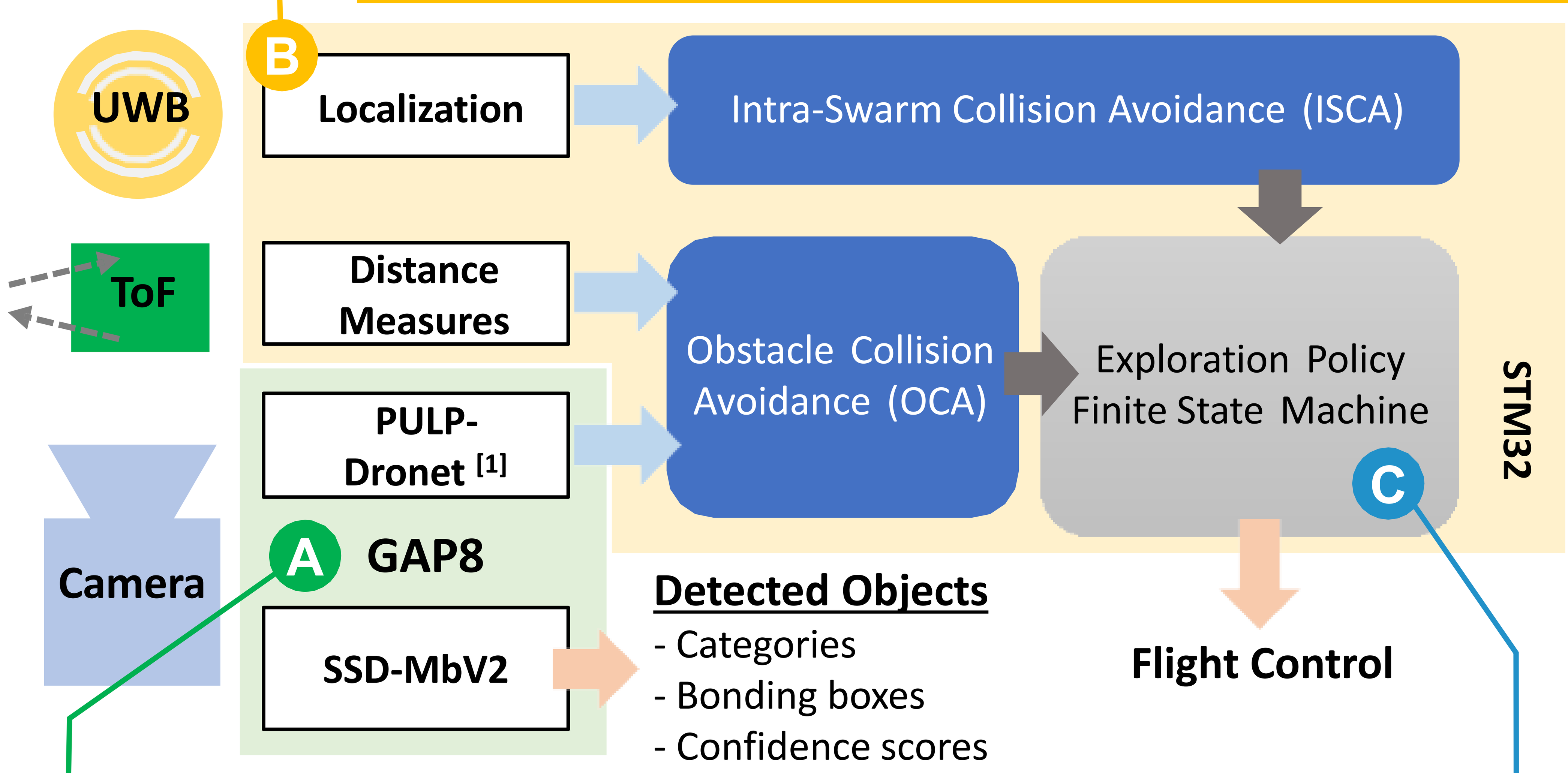
	Standard-sized	Next-generation
Size [⌀, weight]	~50cm / ~ few Kg	~few cm / ~few g
Tot. Power	~ 100 W	~ 5W
Processing device	High-end CPU	Low-power MCU
Cognitive Capacity	Fully autonomous	



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

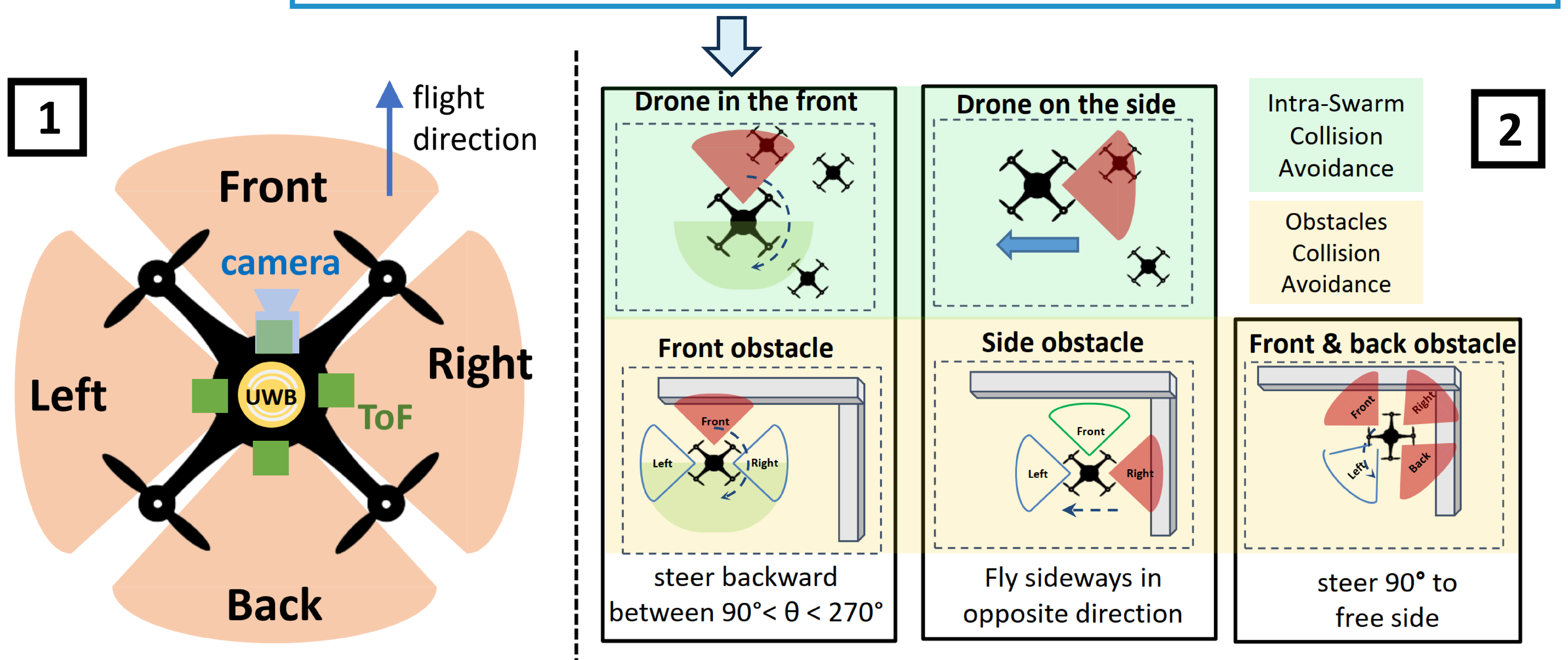
System Design

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



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 interleaving process.

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



[1] System setup [2] Exploration policy based on the multi-sensory collision avoidance logic.

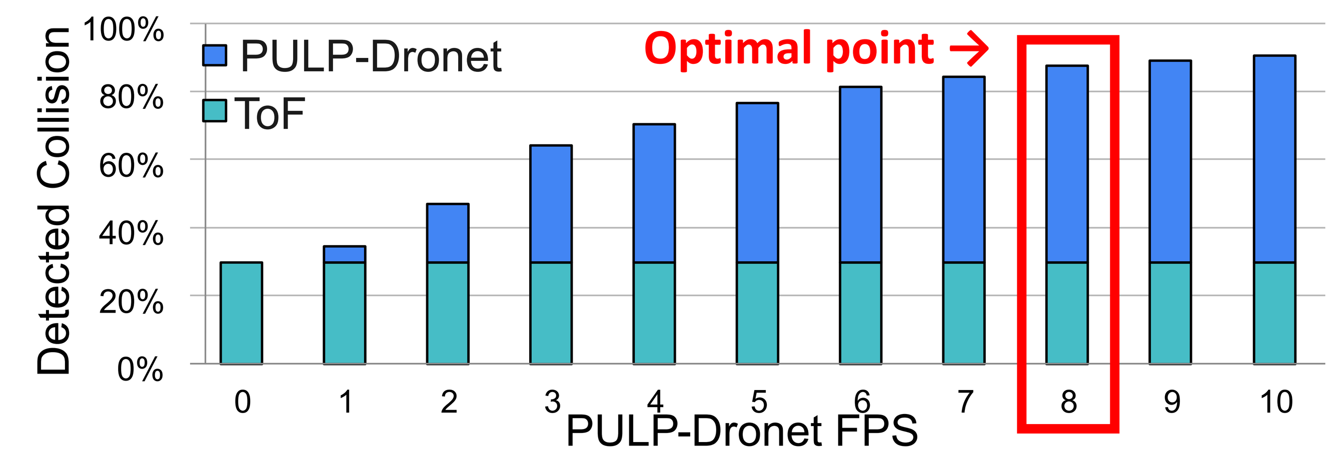
Results

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

Env.	Parameters	SniffyBug	ToF-only	ToF& PULP-Dronet
obstacle free	Crash-free rounds	5 /5	5 /5	-
	Avg. crash/min	0	0	-
	Avg. coverage/min[%]	20.7	22.4	-
obstacle populated	Crash-free rounds	4 /20	3 /20	16 /20
	Avg. crash/min	1.8	1.5	0.2
	Avg. coverage/min[%]	33.2	22.6	10.3
narrow corridor	Crash-free rounds	0 /10	1 /10	7 /10
	Avg. crash/min	2.6	2.4	0.4
	Avg. coverage/min[%]	19.8	45.2	26.7

↑60% ↑70%

▶ 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**

MCU	Task	Throughput [Hz]	Parameters [MB]	Memory [KB]	Power [mW]
STM32	UWB	20	-	0.4	320.1
	ToF	20	-	0.1	286 [6]
GAP8	SSD	1.7	4.67	250	134 [6]
	PULP-Dronet	62.9	0.0832	200.4	100.9
	SSD&PULP-Dronet	1.6	4.7532	250	133.1

Acknowledgement

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[1] Lamberti, Lorenzo et al. "Tiny-PULP-Dronets: Squeezing Neural Networks for Faster and Lighter Inference on Multi-Tasking Autonomous Nano-Drones." *2022 IEEE 4th International Conference on Artificial Intelligence Circuits and Systems (AICAS) (2022)*
[2] Duisterhof, Bardienus Pieter et al. "Sniffy Bug: A Fully Autonomous Swarm of Gas-Seeking Nano Quadcopters in Cluttered Environments." *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (2021)