SensorFly: Controlled-mobile Sensing Platform for Indoor Emergency Response Applications

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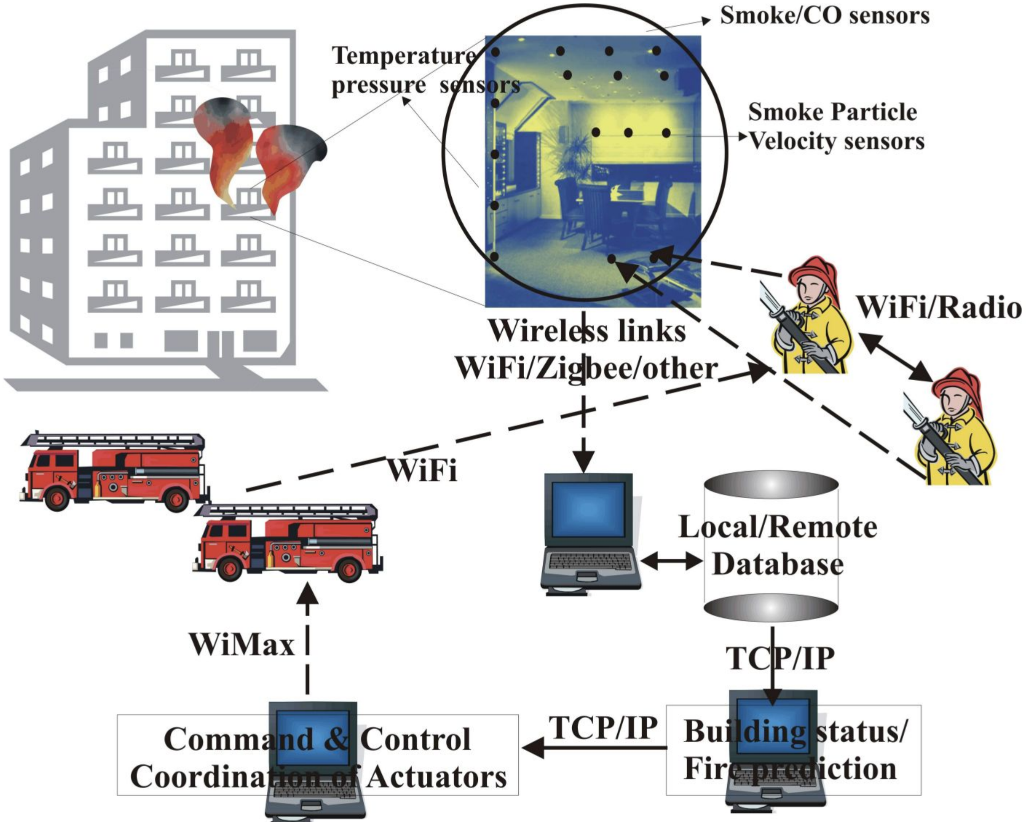
Introduction

Limitation:

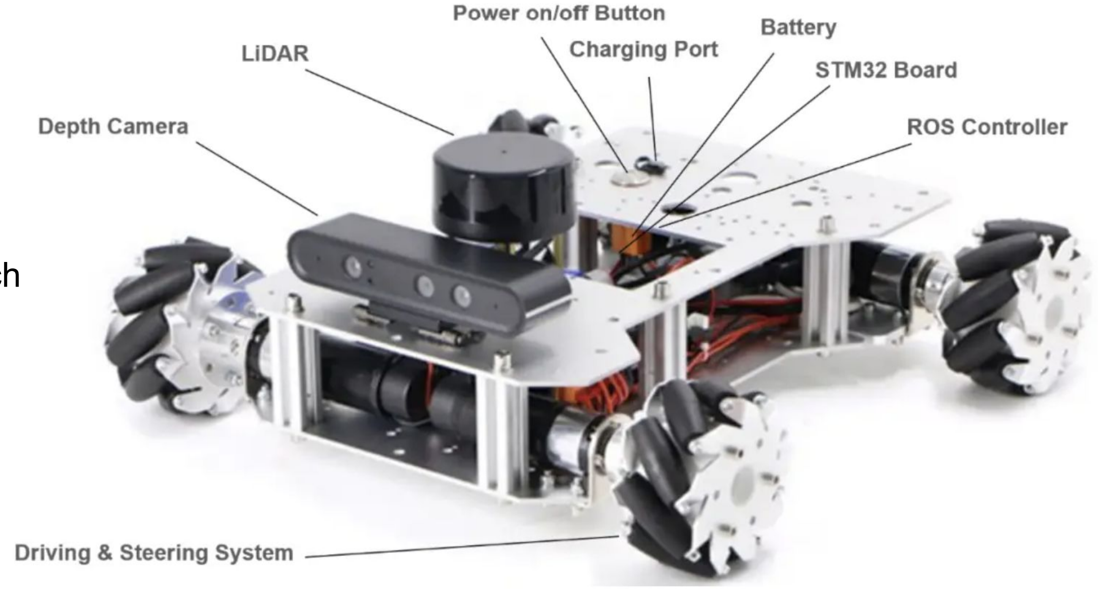
- High Infrastructure & Maintenance Cost
- Low Adaptability & Robustness
- Restricted Spatial Coverage



Introduction

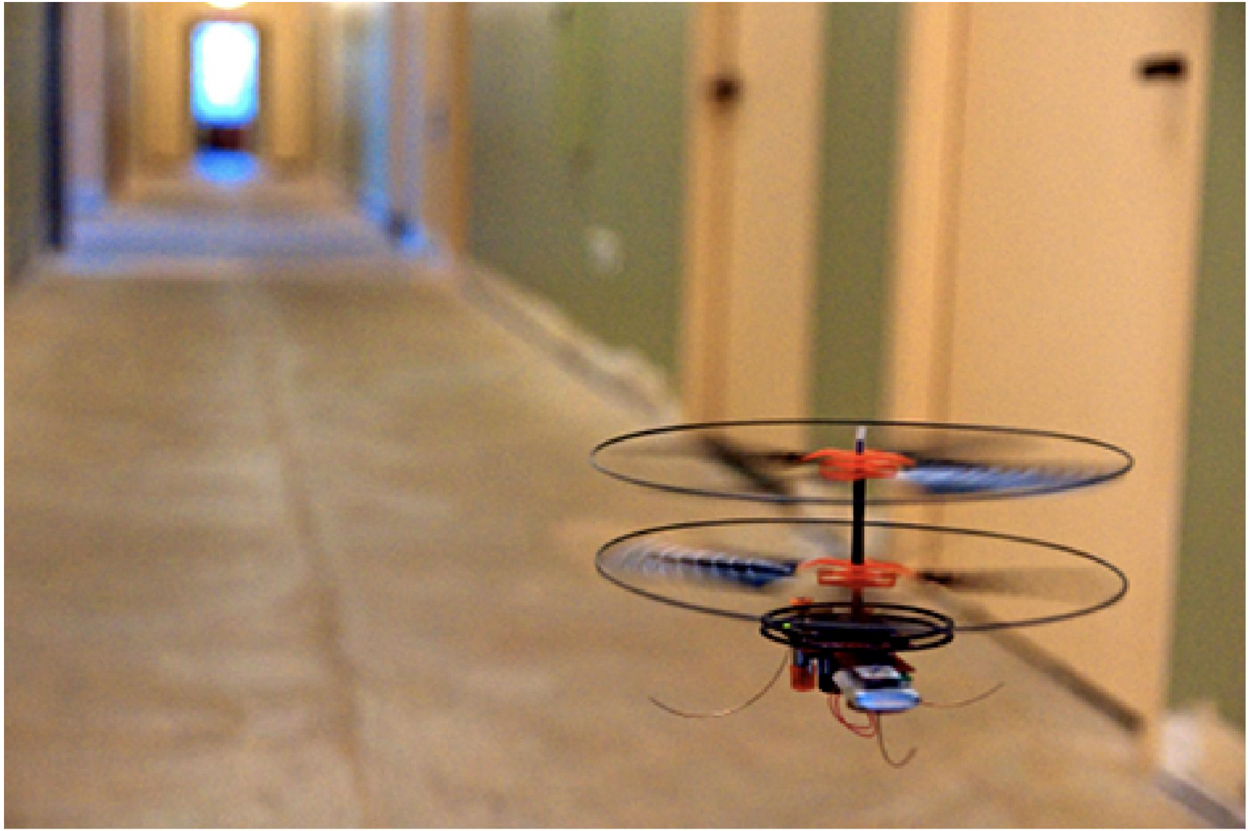
Limitation:

- Limited robustness
- Expensive sensors
- No 3-D sensing, limited reach



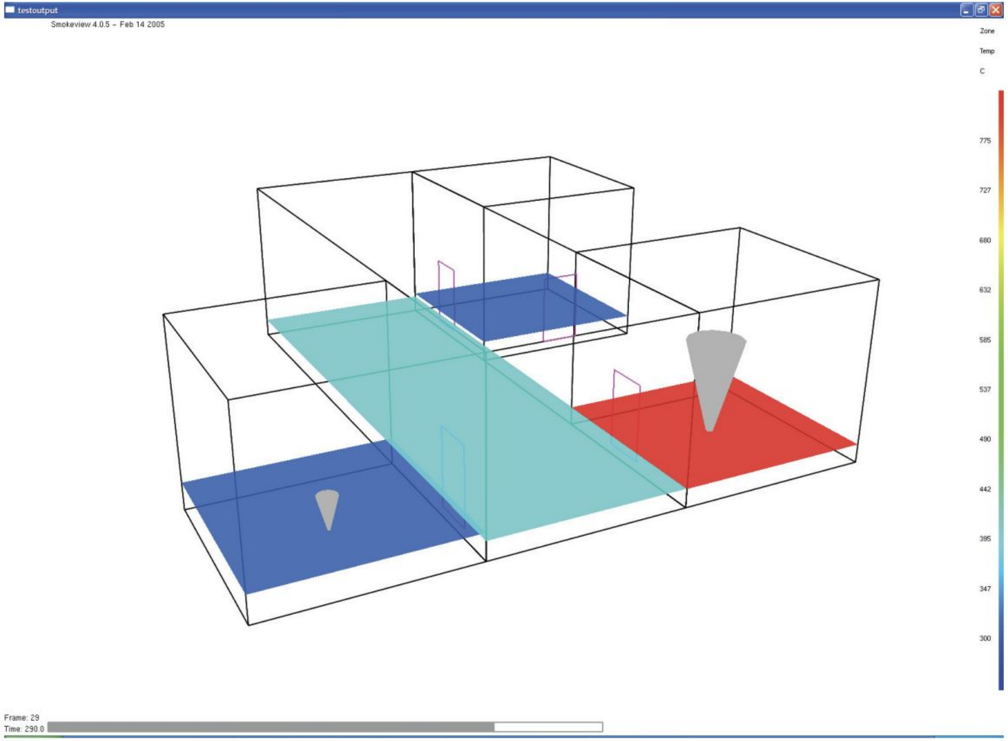
Application

- Low-cost
- lightweight
- Controlled mobility
- Distributed & robust

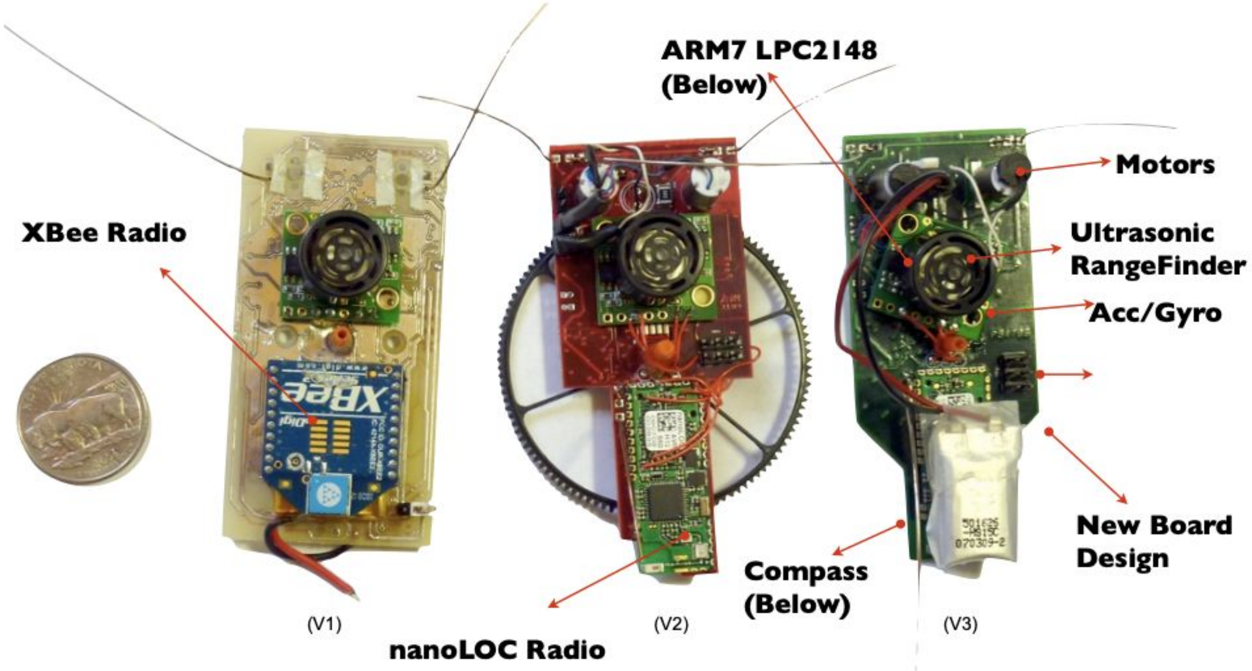


Application

Consolidated Model of Fire Growth and Smoke Transport



Hardware



Key Constraints:

- Cost
- Weight
- Energy
- Interference and Noise

Hardware

	Component	Weight
X	Drive Motors and Propeller Assembly	15 grams
X	130mAh Lithium Polymer Battery	4 grams
	200mAh Lithium Polymer Battery	7 grams
X	Controller Board	10 grams
	Camera Board Add-on	3 grams
	Audio Board Add-on	4 grams
	LED Board Add-on	3 grams
	Ultrasonic Distance Sensor Add-on	4 grams
	Basic SensorFly Total Weight	29 grams
	Absolute Maximum Takeoff Weight	34 grams

Hardware

Table 3: Comparison of Navigational Sensors.

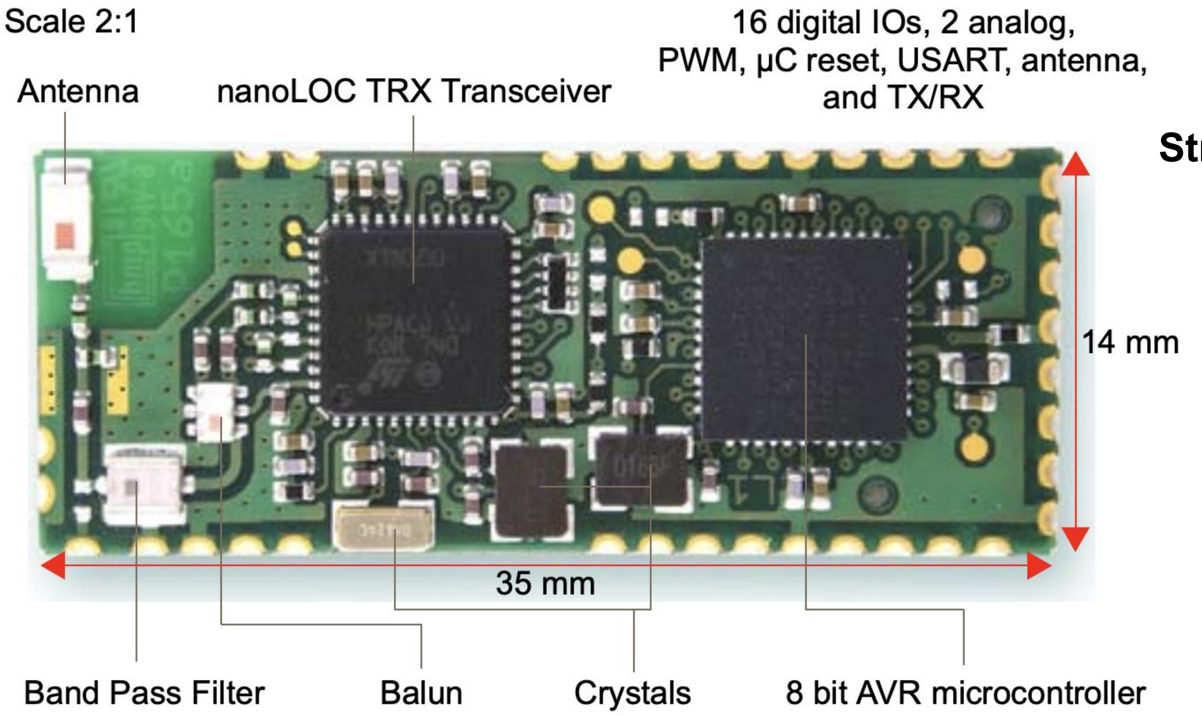
Component	Cost	Weight	Accuracy
Accelerometer	Low cost COTS component	Low < 1g	Analog inertial sensor. Unreliable for distance estimation due to accumulating error. Used to detect collisions.
Gyroscope	Low cost COTS component	Low < 1g	Useful for angular velocity measurement. Unreliable for absolute angular position measurement but not affected by magnetic fields. Used for feedback to for yaw controller.
Compass	Low	Low < 1g	Low indoors due to sensitivity to magnetic fields. Error does not accumulate. Used to provide absolute heading.
Ultrasonic Ranger	Low	Medium ~4g	Fair. Depends on environmental factors such as interference and materials.
Nanotron nanoLoc RToF ranging	Low. Cost is amortized as radio is also used for communication.	Medium. (~4g)	Better accuracy than RSSI based radio-ranging. Less accurate than ultrasound and laser range finders.
Laser Ranger	Medium	High 50g+	High. Not included due to weight constraints.
Vision	High	High	Accuracy depends on operation scenarios. Less effective in presence of smoke. Needs high processing power.

3D compass, a 3-axis accelerometer, a 2D gyroscope

Hardware

Operation	Typical Power Usage
Mobile Mode	6.2W
Stationary Mode	
Data transmission	310mW
Data receive	330mW
Sensing only	225mW
Processing Only Mode	150mW
Idle Mode	1mW

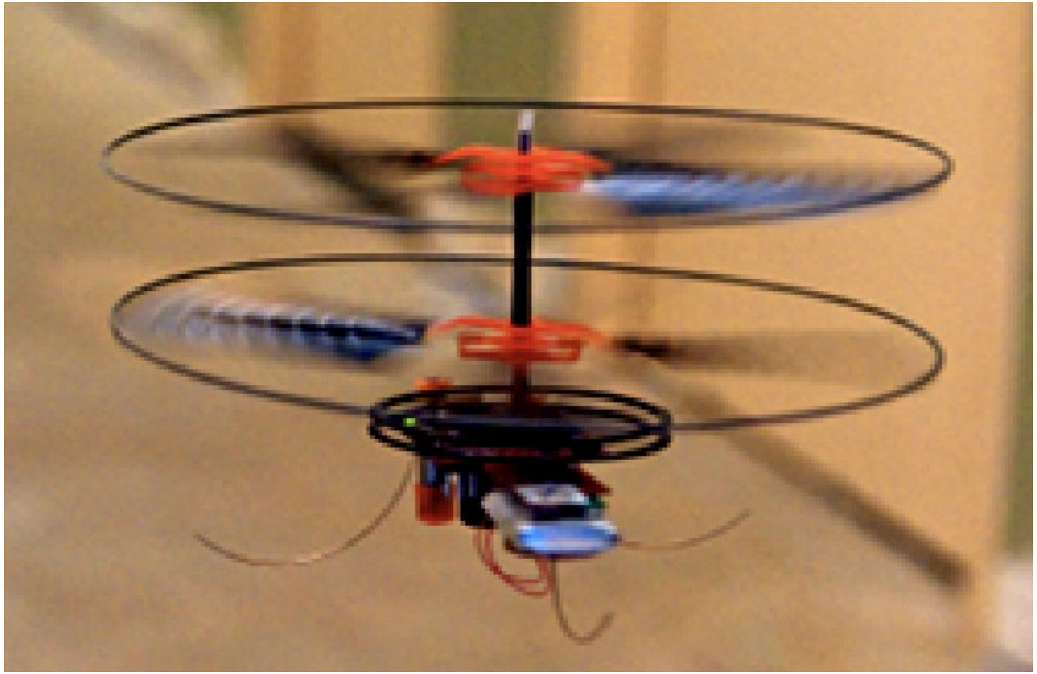
Hardware



Strategy : Component reuse

- Communication
- Round-trip Time-of-Flight radio ranging

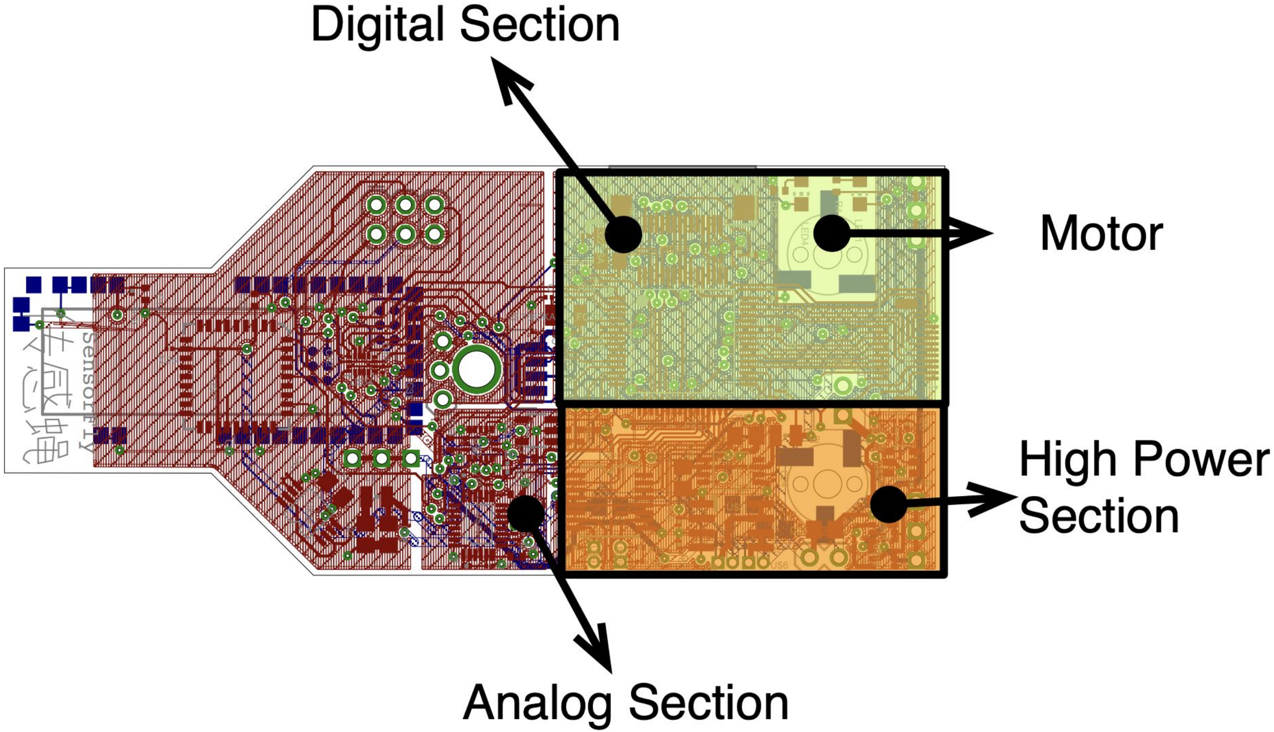
Hardware



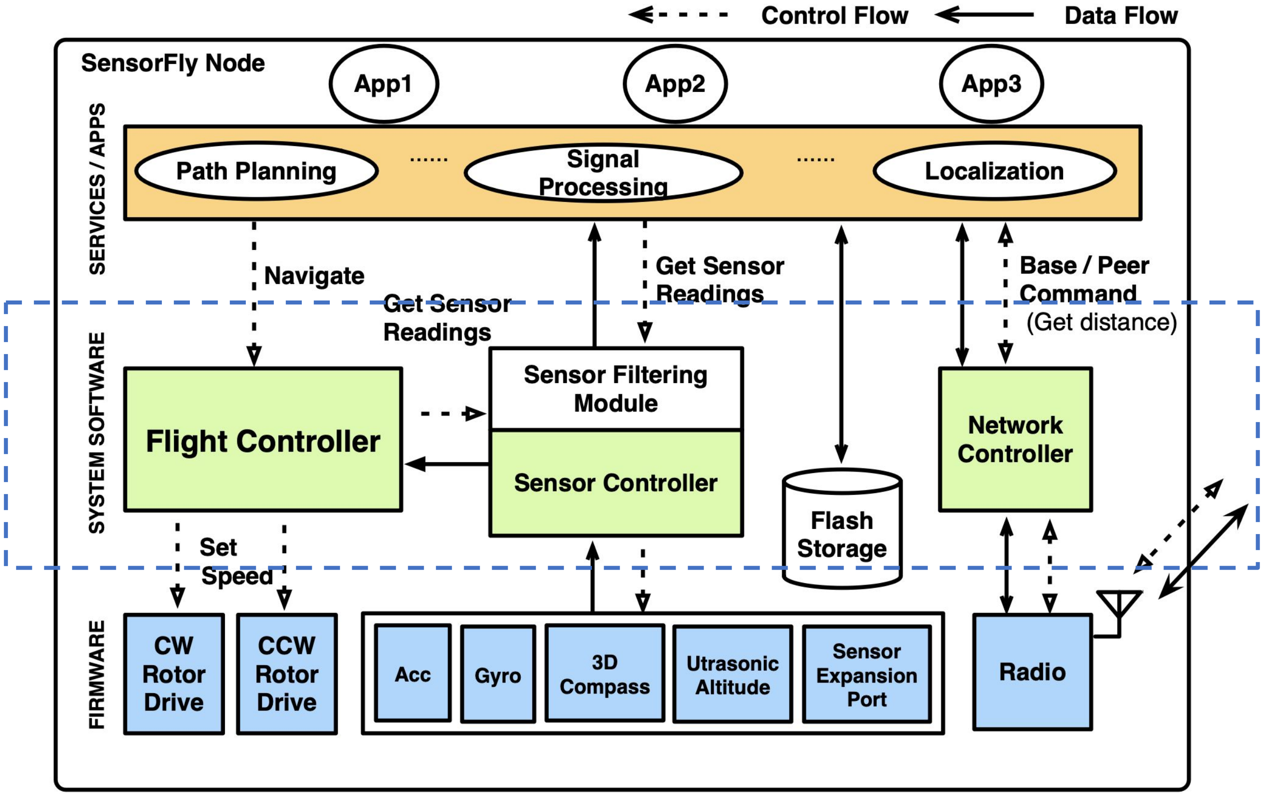
Strategy: Component reuse

- Flying
- Protective buffer

Board Layout



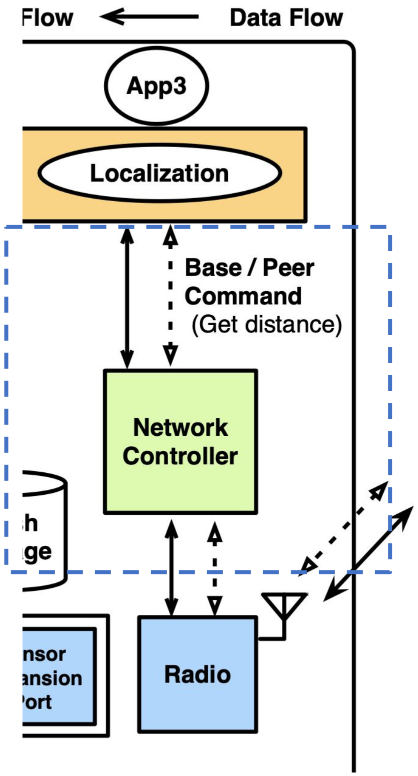
Software Architecture



Node system software:

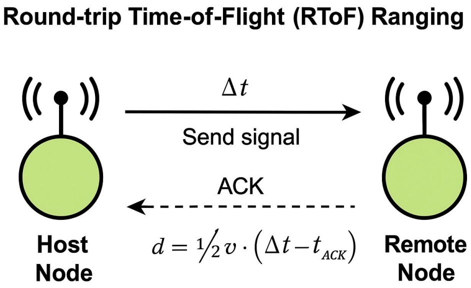
- **Sensor Controller**
- Network Controller
- Flight Controller

Network Controller

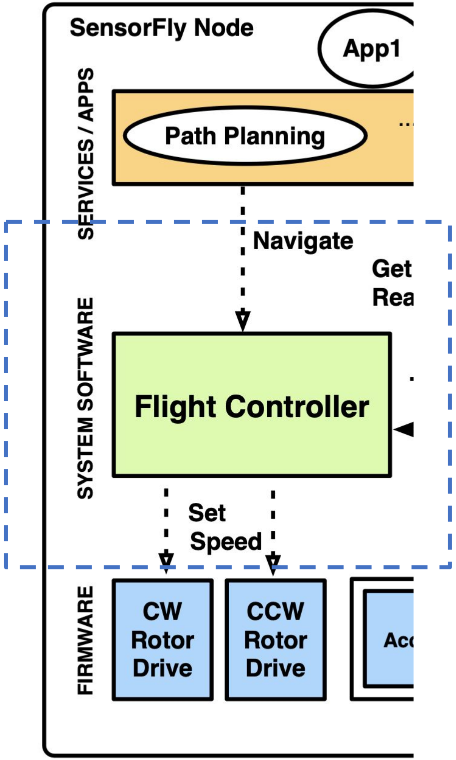


1. Data communication
- Broadcast and aggregate
- Sensor data: ID, TTL(Time-To-Live)

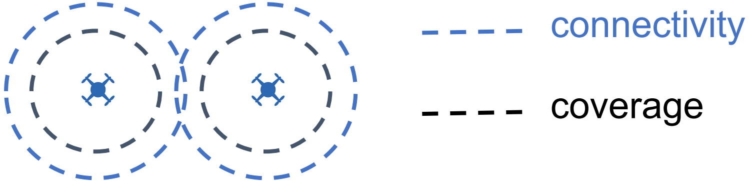
2. Ranging
- Using RToF(Round-trip time-of-flight)based technique
- No need for extra hardware for global clock synchronization



Flight Controller

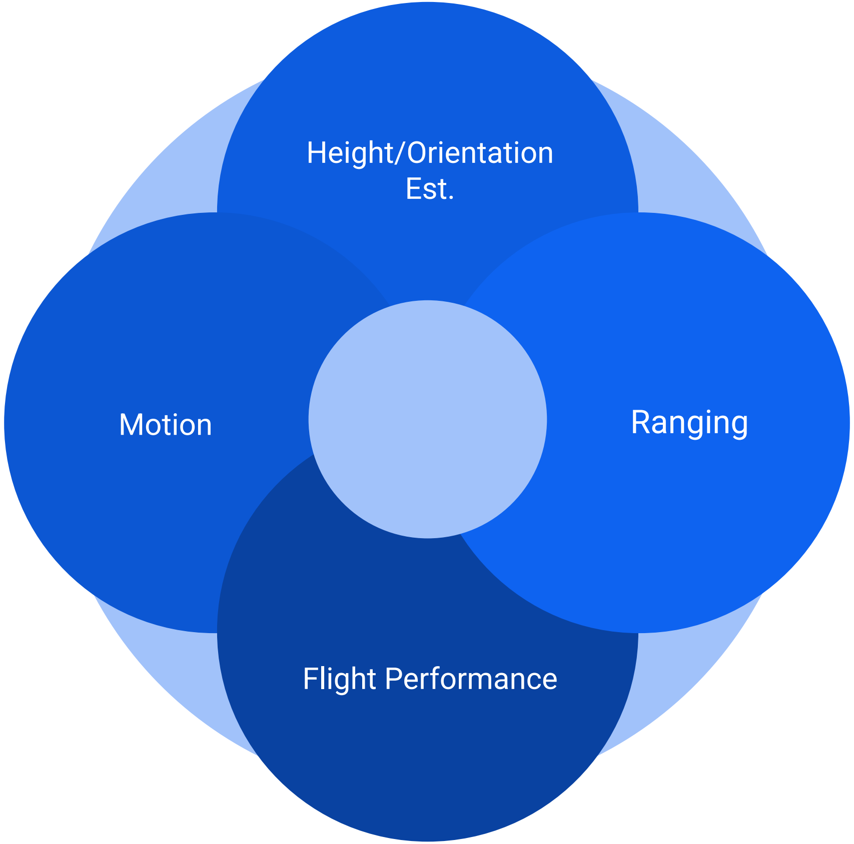


1. Exploration Algorithm -(increasing coverage)
- Biased-Random Walks
- Within connectivity but not within coverage



2. Altitude and Yaw Control
- One PID (proportional-integral-derivative) controller for taking off and maintaining altitude
- Another PID controller for spin modulation
- Forward pose is attained by weight distribution

Implementation and Characterization

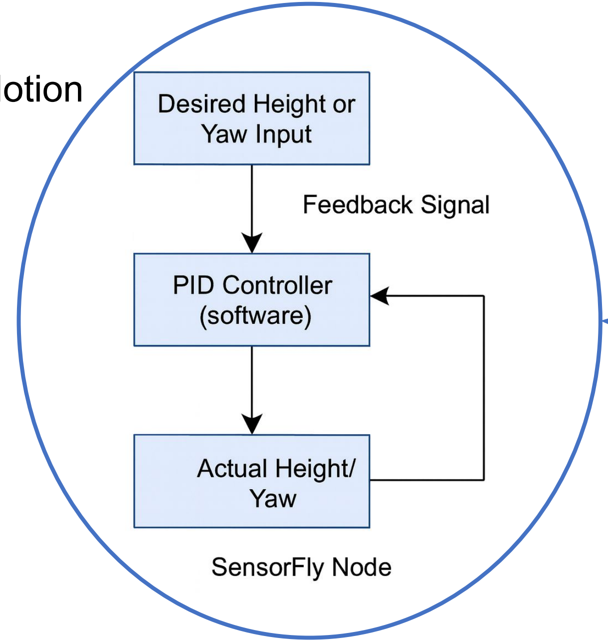


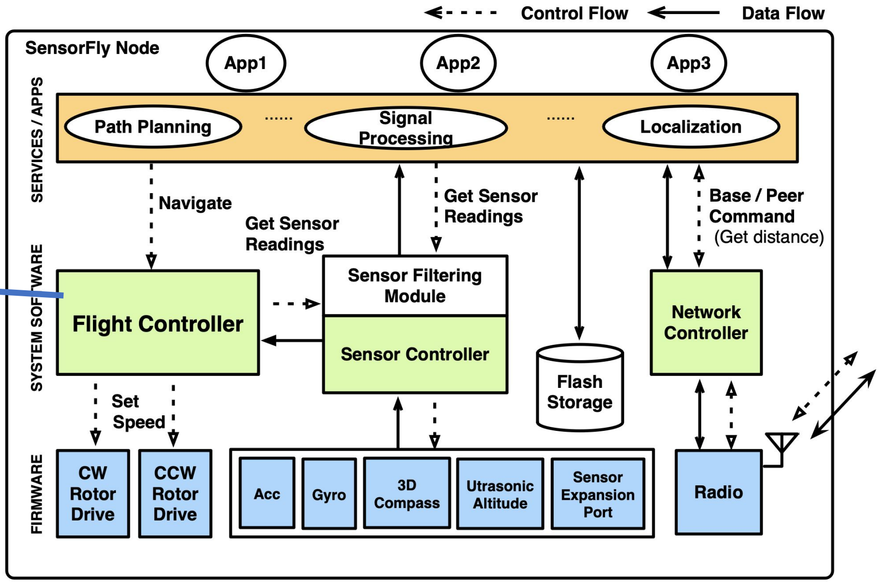
Height/Orientation Estimation and Motion

Orientation estimation: gyroscope and compass(affected by motor)

Height estimation: ultrasonic range finder(affected by building material)

Motion





Characterization - Flight Performance

Achieving stable hover at a given height

Set Height	Maximum Overshoot	Settling Time (70%)	Avg. Steady State Height	Flight Time
1ft.	4ft.	25sec	1.5ft.	6:20min
2ft.	6ft.	40sec	2.5ft.	5:30min
3ft.	6ft.	50sec	3.5ft.	4:50min

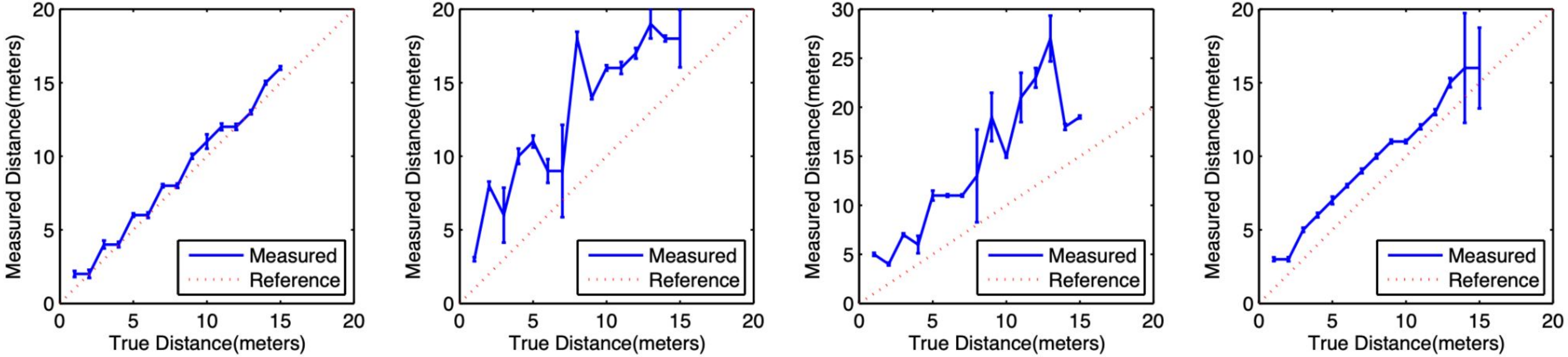
Conclusion: Height higher, duration shorter

Future work:

1. better control strategy
2. longer flight duration

Characterization - Ranging

Radio ranging: Multi-path and Non-Line-of-Sight(NLoS) errors which are defined by specific space configuration so that it cannot be modeled



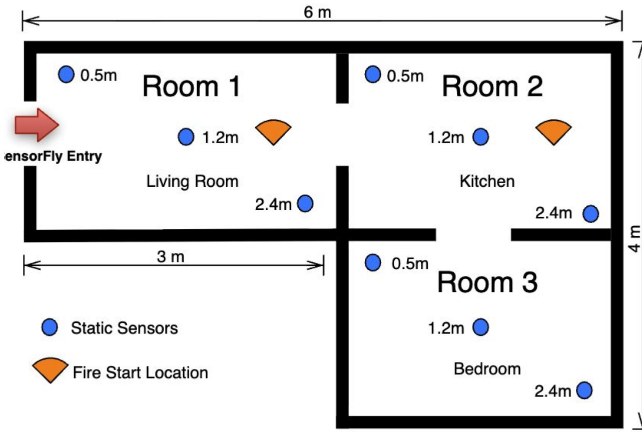
(a) Open Parking Lot (b) Metallic Cubicle Area (c) Lounge (d) Hallway

Although average error is high (4.2m), it shows a high correlation (94%).

Exploration algorithm works

Experimental setup

- Baseline: statically pre-deployed sensors
- Setup: CFAST, a fire simulator by NIST
- Metrics:
  - Average Model Error: RMS error of predicted model
  - Spatio-Temporal Percentage Coverage: Ratio of the number of readings in the height-time plane to the max possible resolution
- Ablation study: assume random node failures



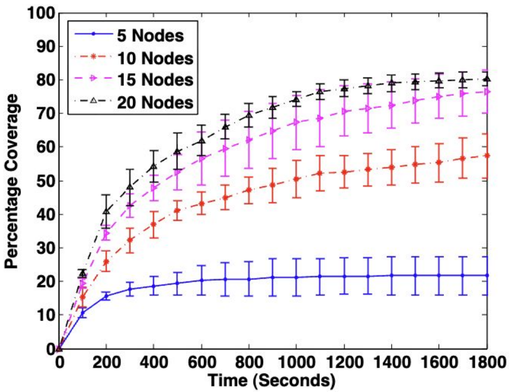
Evaluation results

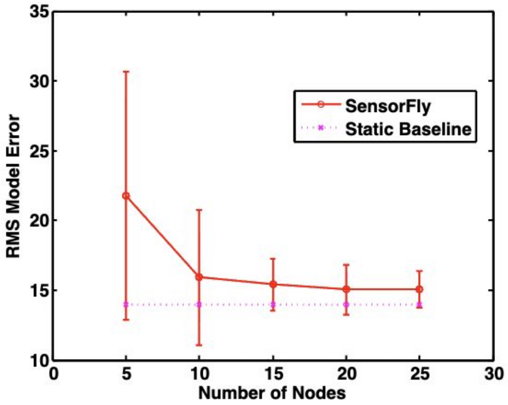
(a) RMS Model Error vs. # of Nodes: 14% stable errors

(b) Coverage vs. # of Nodes: linear increase

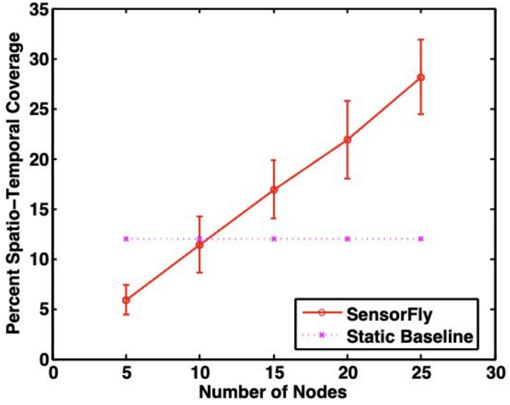
(c) RMS Model Error vs. Node Failure: sub-linear errors

(right) Coverage of different # of nodes over time

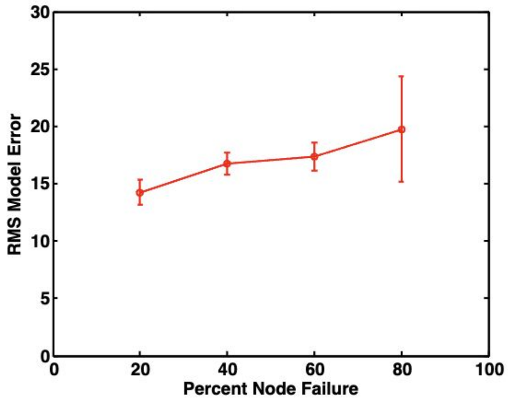




(a)



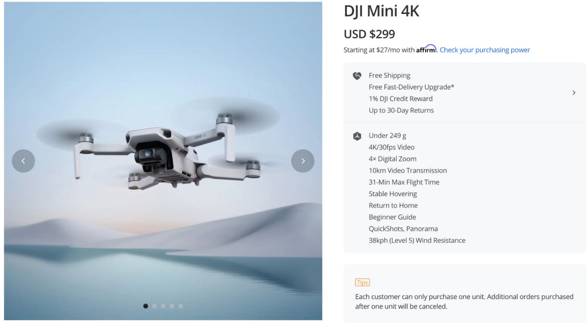
(b)



(c)

Impacts on the latest research & industry

- Costs: the COTS UAVs decrease dramatically during last decade [1]
- Battery life: improves to up to 1hr
- Applications: extend to outdoor wide area for aerial imaging [2], first responders [3], smart agriculture [4], military etc.
- Long-range large-bandwidth communication: Cellular/5G, MavLink [5], 2.4GHz band channel etc. for 4k video streaming up to 10km range



[1] DJI. 2025. DJI Mini 4K. DJI Store. Retrieved October 6, 2025 from https://store.dji.com/product/dji-mini-4k?vid=166281

[2] Arturo Miguel Russell Bernal, Walter Scheirer, and Jane Cleland-Huang. 2024. Nomad: a natural, occluded, multi-scale aerial dataset for emergency response scenarios. In Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision (WACV 2024), 8584–8595.

[3] National Institute of Standards and Technology (NIST). 2025. Drones in Disaster Zones: How Advanced 3D Mapping Technology Can Help First Responders Save Lives. NIST Taking Measure Blog. Retrieved October 6, 2025 from https://www.nist.gov/blogs/taking-measure/drones-disaster-zones-how-advanced-3d-mapping-technology-can-help-first

[4] Chunhua Zhang and John M. Kovacs. 2012. The application of small unmanned aerial systems for precision agriculture: a review. Precision Agriculture 13, 6 (2012), 693–712. https://doi.org/10.1007/s11119-012-9274-5

[5] MAVLink Development Team. 2025. *MAVLink Guide*. Retrieved October 6, 2025 from https://mavlink.io/.

Impacts on the latest research & industry

- “Drones Guiding Drones: Cooperative Navigation of a Less-Equipped Micro Aerial Vehicle in Cluttered Environments” by Pritzl and et. al., IROS 2024
  - “Leader” drone builds a map and plans safe trajectories, then guides a less-equipped micro aerial vehicle to navigate autonomously through cluttered, GNSS-denied environments.

- “Decentralized Swarm Trajectory Generation for LiDAR-based Aerial Tracking in Cluttered Environments” by Yin and et. al., IROS 2023
  - A decentralized algorithm for UAV swarms using LiDAR-based sensing to generate collision-free trajectories for aerial target tracking in cluttered environments.

- Multiview Aerial Visual Recognition (MAVREC): Can Multi-view Improve Aerial Visual Perception? By Dutta and et. al. , CVPR 2024
  - Combining aerial and ground views helps drones recognize objects more accurately than using aerial images alone