Indoor Micro-UAV Navigation with Limited Sensing

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Introduction

Problem Statement

- **This project develops a micro-UAV system suited to flying through a doorway w/o full localization**

External Localization Method	Drawback
GPS	Weight, cost, limited to outdoors
Motion Capture System	Limited to one area, cost
Onboard sensor fusion	Weight, cost, precision

- Challenge: standard Visual-Inertial Navigation Systems (VINS) fail due to low resolution & IMU drift

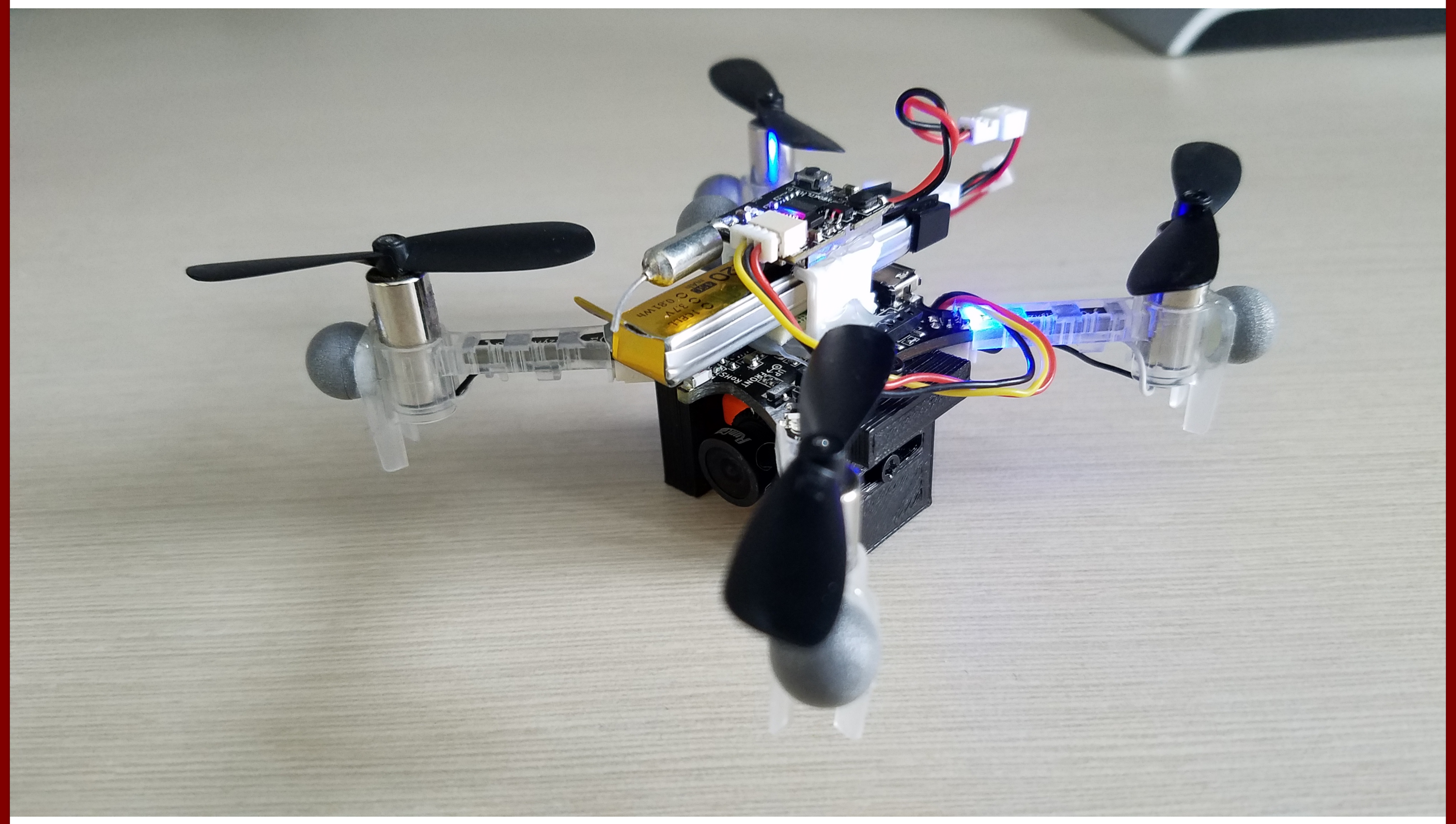


Figure 1: Crazyflie platform (27g). Onboard inertial measurement unit (IMU) is on central control board, and 480x640 resolution camera mounted below

Methodology

Two methods developed for each of following tasks: (1) detecting doors in images, (2) flying through detected door. Methods validated on novel datasets/test flights.

- **Door Detection via Hough Transform**:

Detect major lines in image → Group into pairs of parallel lines, perpendicular pairs form candidate doors (fig 2c) → Candidate closest to standard door aspect ratio is detection

If no candidates, previous candidate is tracked

- **Door Detection via Convolutional Neural Network (CNN)**:

$$f(image) = door\ location, confidence$$

Network formed of convolutional operations

- **PD Control on Door Detection**

$$E = Center\ Of\ Image\ - Center\ of\ Door\ in\ Image$$

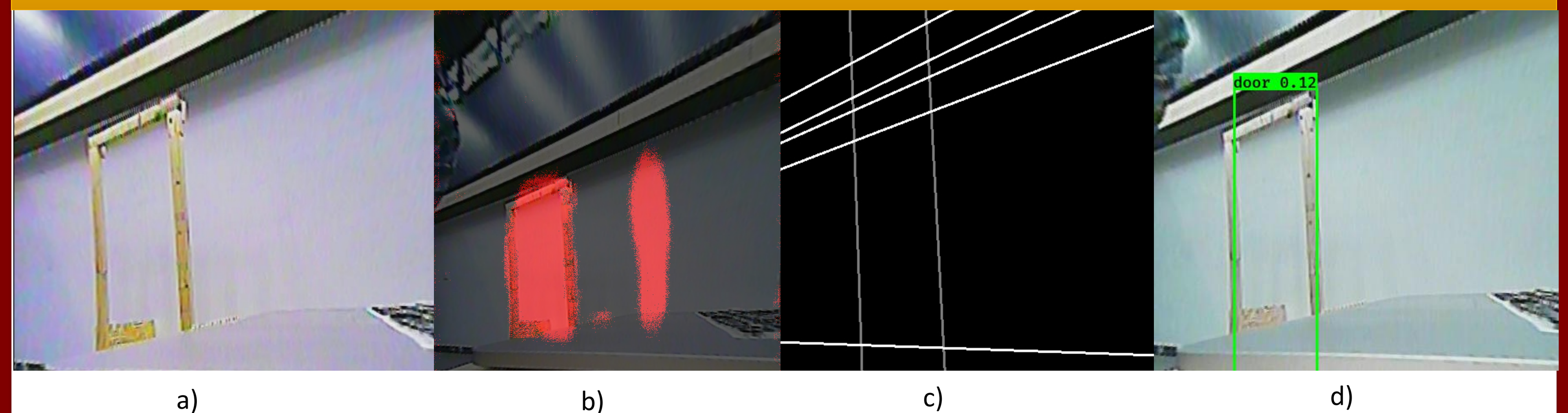
$$\text{UAV control input} = K_p * E\ + K_D * \frac{dE}{dt}$$

- **Control Recurrent Neural Network (RNN)**:

$$f(door\ location, IMU, time) = UAV\ control\ input$$

Network of Gated Recurrent Units (memory cells - deal w/ velocities & past actions)

Door Detection



a) b) c) d)

Figure 2:
a) Plywood door b) Instance Segmentation
c) Hough Lines detected d) Tiny-YOLO detection

Hough Transform

- Many spurious lines due to lighting, noise, scene clutter. Suppression needed for accurate candidate selection
- Tuned to perform well on test Dataset 1 (plywood door, clean environment) (fig 2c), failed to generalize well to Dataset 2 (real doors, cluttered environment)
- Difficult to determine candidates when door is seen from an oblique angle, since aspect ratio changes

CNN

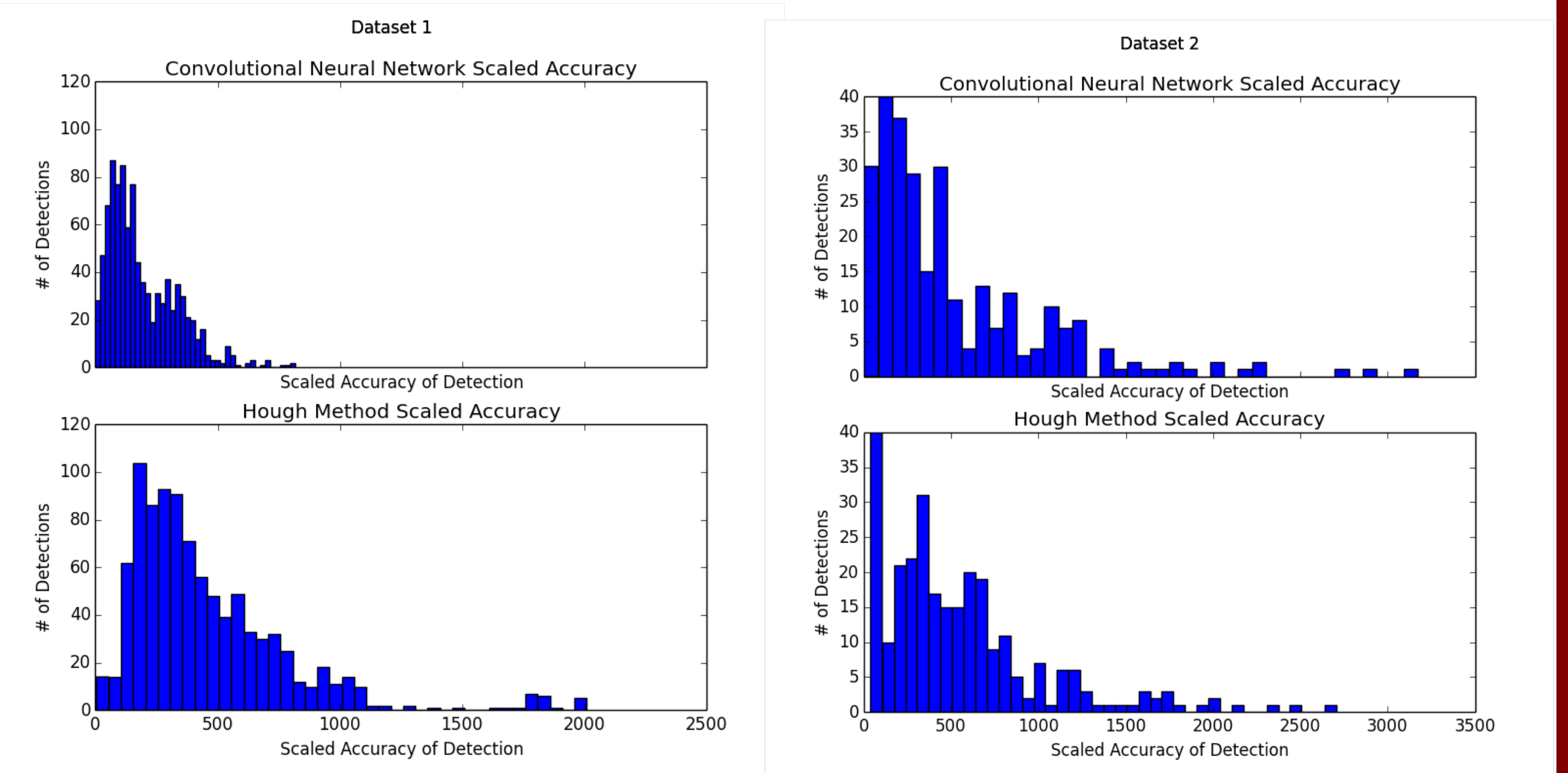
- Full segmentation (Figure 2b) attempted, deemed too slow for use
- CNN selected is Tiny-YOLO, a bounding box instance detector (fig 2d) [1]
- Trained on door images from ADE20K dataset [2]
- Generalized to and outperformed (time & accuracy) Hough method on both test datasets

Dataset 1 Timing plywood door, clean environment (fig 2a)	Hough Method	CNN Method	Dataset 2 Timing Real doors, cluttered environment	Hough Method	CNN Method
Mean sec/image	1.11	0.089	Mean sec/image	0.08	0.072
σ sec/image	1.99	0.024	σ sec/image	0.02	0.009

Accuracy Measurement

- Full bounding box comparison not done (only center of door (x, y) important for flight)
- Scale by true door area to weigh error more heavily if door is far away – **lower accuracy score is better**

$$Accuracy = \frac{\sqrt{(y_{true} - y_{predicted})^2 + (x_{true} - x_{predicted})^2}}{True Door Area}$$



Door Flight

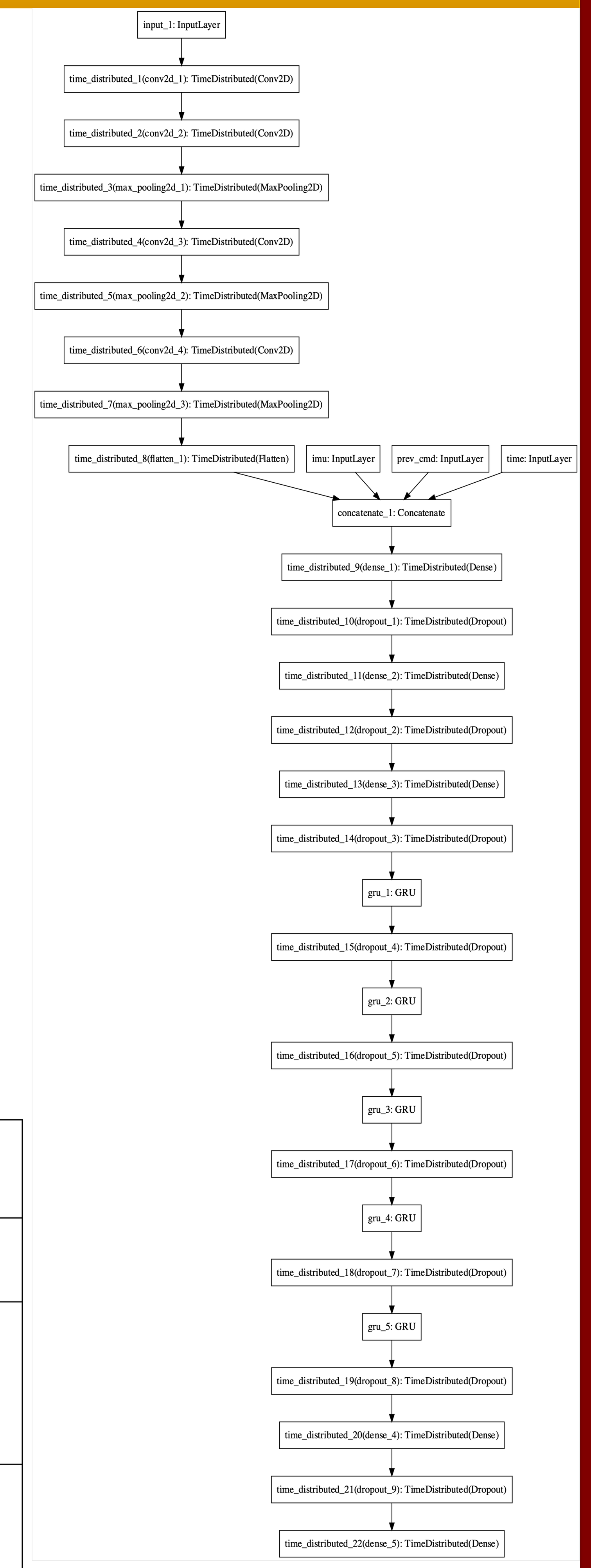


Fig 4: Recurrent Network Architecture

Goal:

Fly through door without external knowledge of UAV position

PD Control

- Able to successfully make it through door
- Uses simulation specific door detection
- Difficulties when door starts near edges of image – yields strong oscillations

RNN Control

- Simulated waypoint following algorithm flies Crazyflie through door for training data collection
- Network: small convolutional section for image, combined with other sensor data, followed by Gated Recurrent Units

Testing

- PD parameters tuned through test flights from zero location, RNN trained on flights from zero location
- 20 flights simulated from zero location, 20 flights from arbitrary location

	PD Control	RNN Control
Stable flight	Yes	Yes
Success rate from tuned position	65% (13/20)	Loops w/o finding door
Success rate from arbitrary position	15% (3/20)	Loops w/o finding door

References

Acknowledgements

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References

[1] Redmon, J., & Farhadi, A. (2017). Tiny yolo.
[2] Zhou, B., Zhao, H., Puig, X., Fidler, S., Barriuso, A., & Torralba, A. (2017). Scene parsing through ade20k dataset. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition.