Indoor Micro-UAV Navigation with Minimal Sensing

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April 30, 2019

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Outline

Project Definition & Success Criteria

- Fly through door
- Arbitrary initial location
- Low-quality sensors

  (Camera, IMU)
- 27g weight (42g w/ payload)

Success: <20% failure rate

Source: `https://www.bitcraze.io/crazyflie-2/`

Background: UAV Flight

- Autonomous navigation in constrained spaces
  - GapFlyt
- Small scale UAV control + external sensors
  - Crazyswarm
- High level RNN controller

(a)

(b)

Source:

Sanket et al. (2018)

Debord et al. (2018)

Background: Door Detection

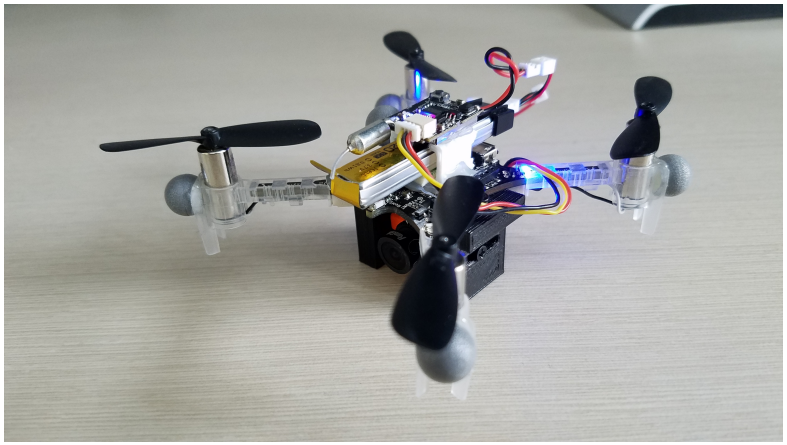
- Networks: segment/bounding box
  - U-Net
  - MobileNet (V2)
  - YOLO (Tiny)
- Non-learning methods
  - Corner, line, edge detection
  - Fuzzy logic
- Knowledge of full door- overkill for navigation?

Source: Akgul (2015), Ronneberger et al. (2015), Howard et al. (2017), Muñoz-Salinas et al. (2004), Redmon and Farhadi (2018)

Project Overview

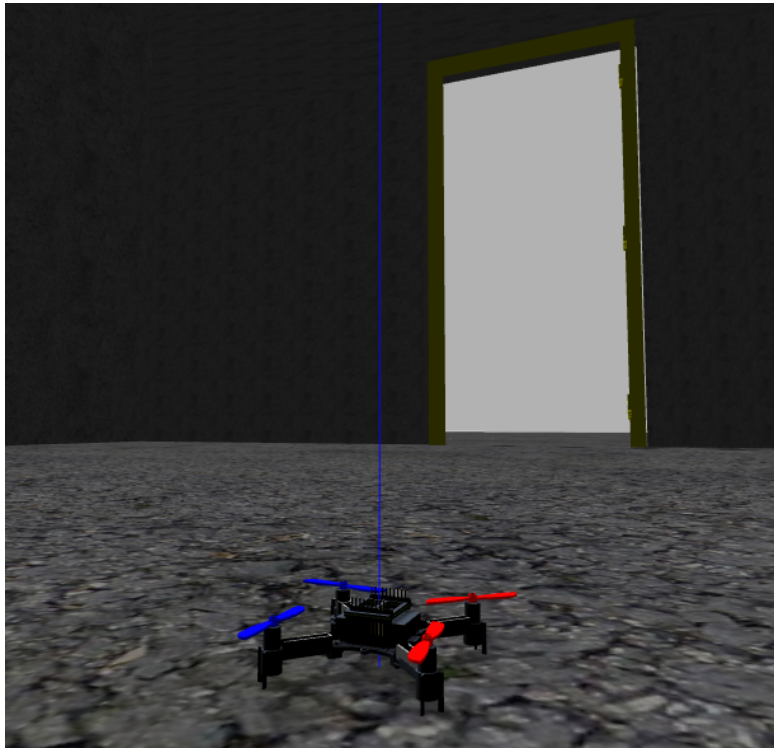
- Initial setup
  - Motion capture
- Door detection
- Independent Flight

Initial Setup

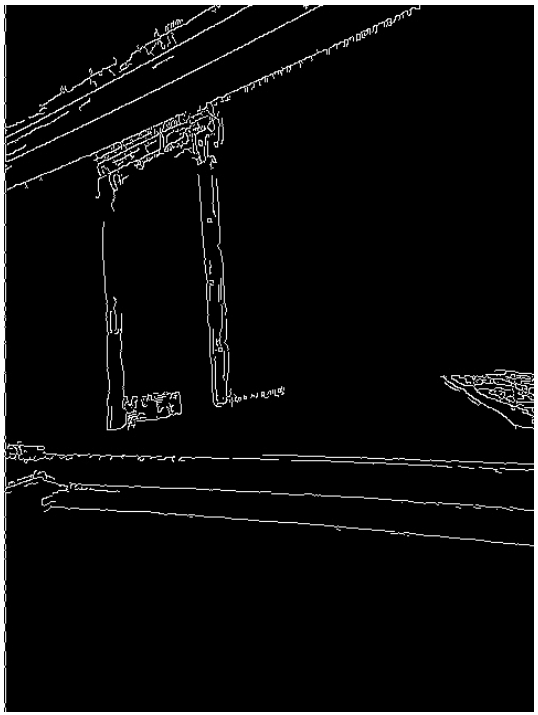


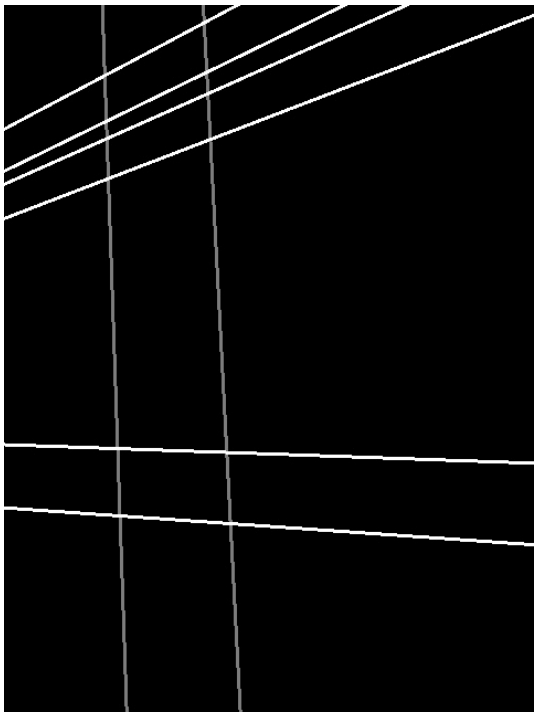
- Payload redesign & test flights
- Ground truth algorithm simulated & VICON implementations

Waypoint Navigation

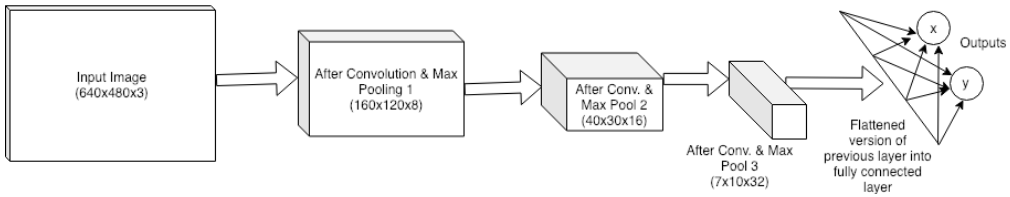


Door Detection - Hough Transform





Door Detection - Convolutional Neural Net



- Small networks- ground station resources
- U-net, Tiny YOLO v3, MobileNet, own design

Door Detection - YOLO

- Small
- Fast
- Modified Loss Function

$$\sum_{i=0}^{48}\Bigg(\lambda \mathbb{1}_i^{\text{obj}}\big((x_i-\hat{x}_i)^2+(y_i-\hat{y}_i)^2+(\sqrt{w_i}-\sqrt{\hat{w}_i})^2+ (\sqrt{h_i}-\sqrt{\hat{h}_i})^2\big)+\sum_{c\in\text{classes}}(p_i(c)-\hat{p}_i(c))^2\Bigg) \tag{1}$$

Redmon and Farhadi (2018)

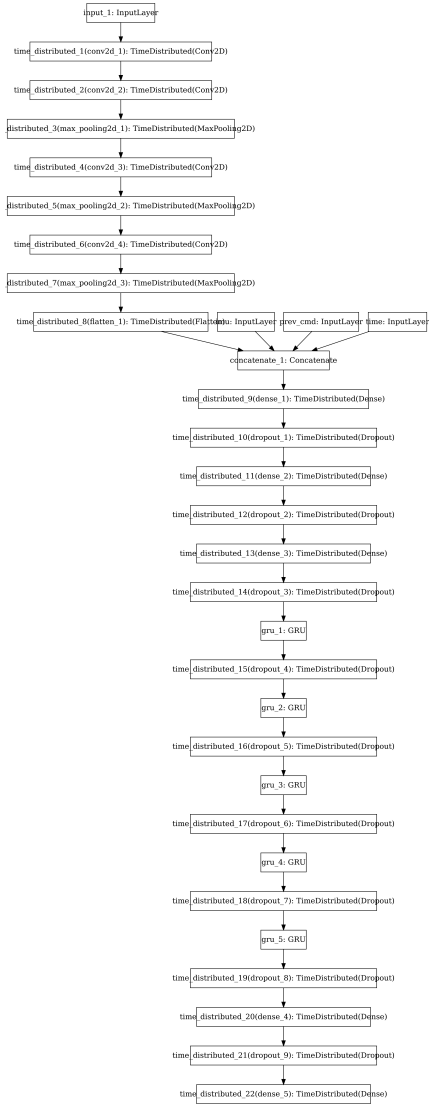
Independent Flight - PD Control

- $RollError = x_{ImageCenter} - x_{DetectedDoorCenter}$
- $ThrustError = y_{ImageCenter} - y_{DetectedDoorCenter}$
- $Command = K_p * Error + K_d * \frac{dError}{dt}$

Independent Flight - Recurrent Neural Network

- Hundreds of ground truth flights recorded
  - Inputs: IMU, image, time
  - Output: Roll/Pitch/Thrust/Yaw-rate
- Image - convolutional section
- Inputs/Outputs normalized
- Gated Recurrent Units (GRU) - memory

Chung et al. (2014)



Door Detection - Timing Comparison

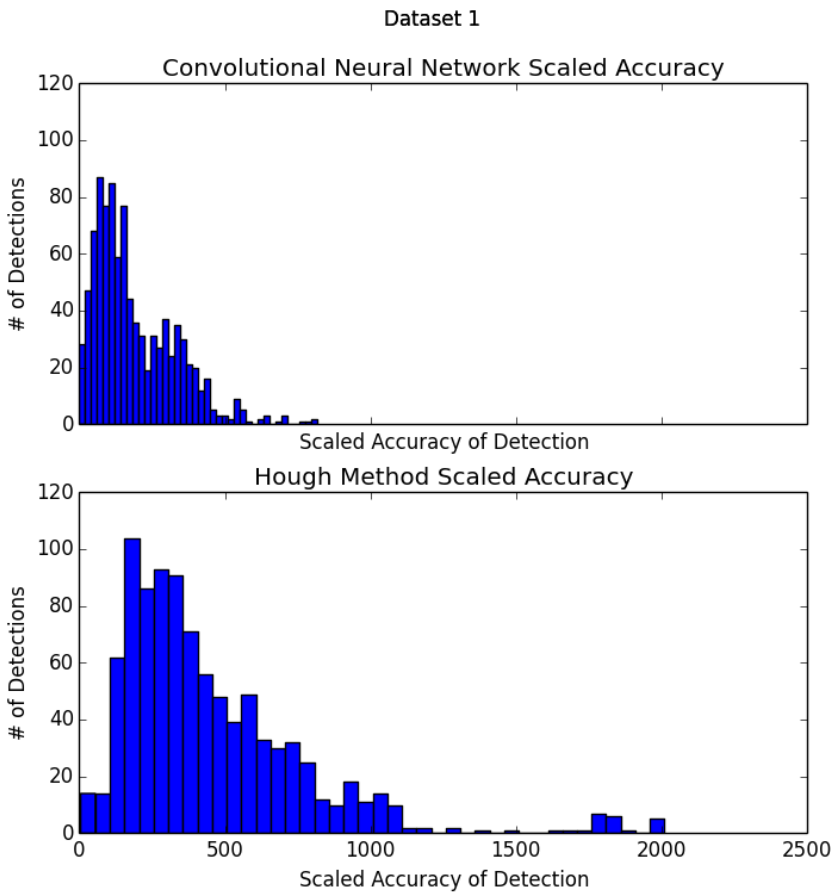
On fake door set:

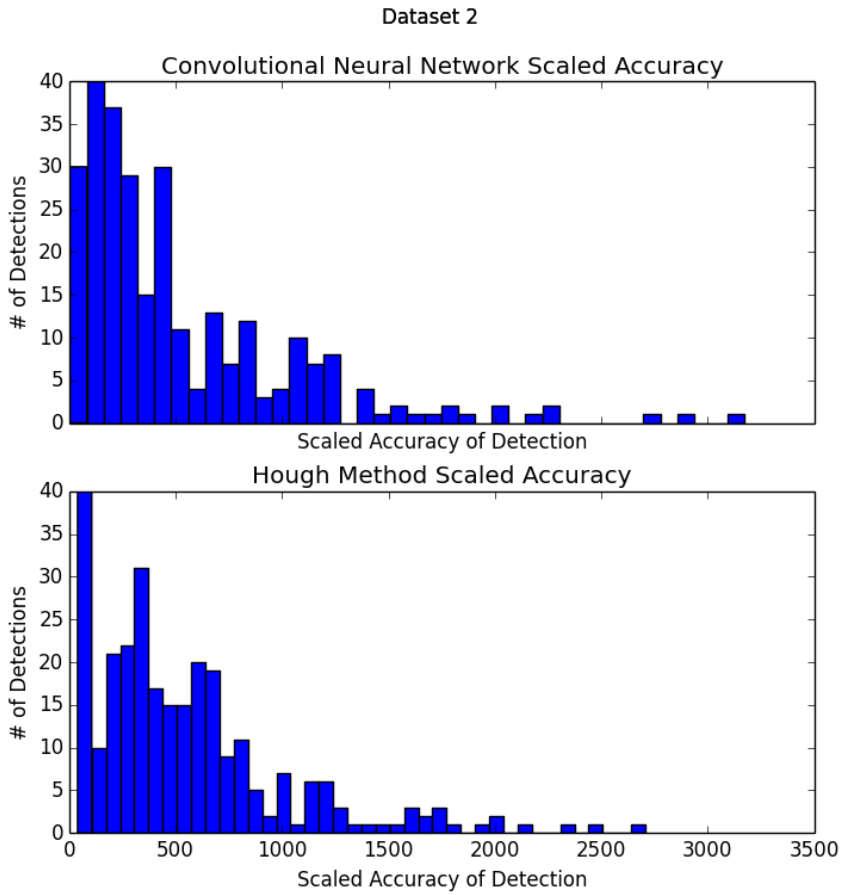
	Hough Method	CNN
Mean msec/image	1.11	0.89
Std. dev. msec/image	1.99	0.024

On real door set:

	Hough Method	CNN
Mean msec/image	0.08	0.072
Std. dev. msec/image	0.02	0.009

Door Detection - Accuracy Comparison



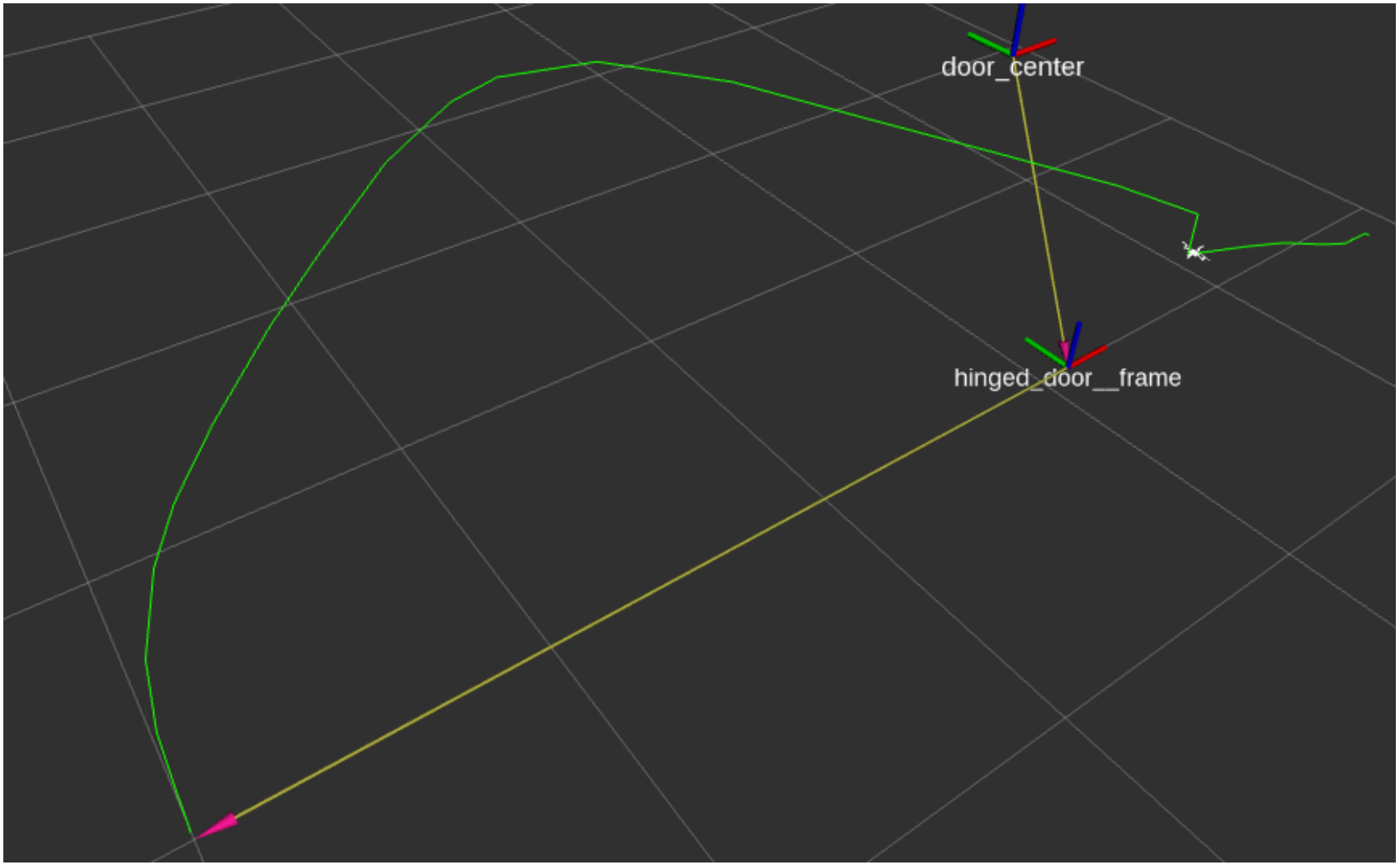


Independent Flight - Success Comparison

- Zero location selected
  - PD controller tuned from zero location
  - Network trained on flights from zero location
- 20 flights from zero location, 20 from arbitrary location

	PD Control	RNN Control
Stable Flight	Yes	Yes
Success rate from zero location	65% (13/20)	Loops w/o finding door
Success rate from arbitrary location	25% (5/20)	Loops w/o finding door

Independent Flight - Successful Flight



Conclusion

- Explored intersection of small size, auto navigation
- Compare methods for door detection
  - CNN more accurate, faster
- Compare methods for independent flight
  - PD controller capable of navigating UAV through door based on door detection

Questions

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Simulation

- Gazebo Simulator
- Input/Output same form as real Crazyflie (SITL)
- Noisy, low resolution camera
- Noise IMU
- Delay to mimic data down-link

Motion Capture

- VICON
- Set of cameras
- Track balls on desired object
- Provide orientation/position but only w/i tracked space
- Safety net: bad UAV orientation/path = shut down

Source: Josinski et al. (2014)

Hough Transform

- Edge detector
- Parametrize line:
- $r = x * cos(\theta) + y * sin(\theta)$
- For each edge point: determine all r, θ solving above, increment table
- Maximums of table give lines majority of points agree on