

Real Time, Onboard-only Landing Site Evaluation for Autonomous Drones

PhD Thesis Proposal

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Reykjavík University

March 2022



Presentation Structure

(1) Introduction

- Problem description and motivation
- State of the Art

(2) Completed/ongoing projects

- Initial proof of concept attempt
 - Continuation of master thesis (tested in simulation)
- Fiducial marker modifications
- Proof of concept

(3) Research Plan

- Methods
- Challenges and risk analysis



Introduction



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“Human-assisted landing”



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- What data do autonomous drone landing methods need?
- How can those methods execute in real time onboard a drone?



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 - Optical flow (requires motion)
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Completed and Ongoing Projects



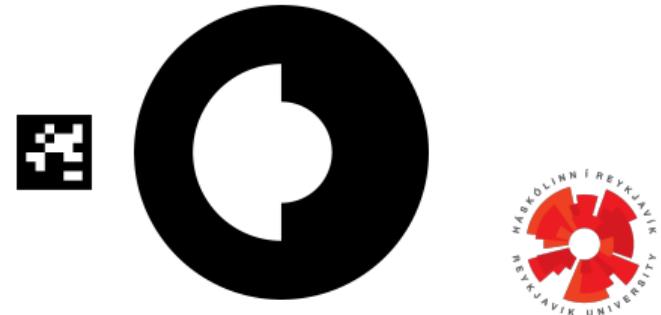
Test Hexacopters

- Two Tarot 680 hexacopters
- For real-world proof of concept of master thesis simulations.



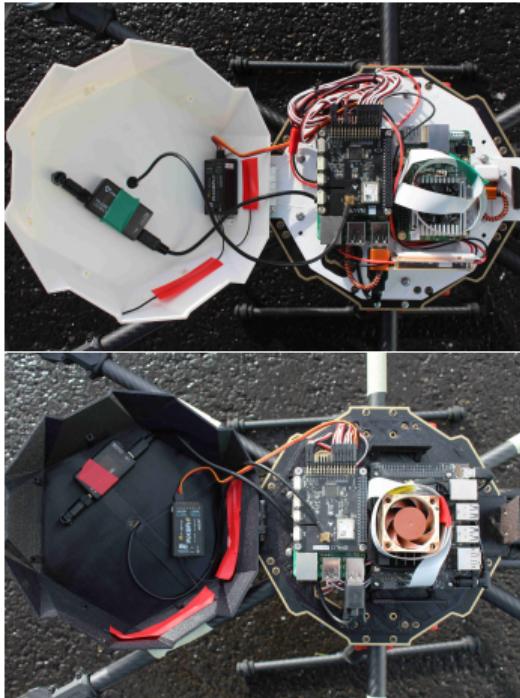
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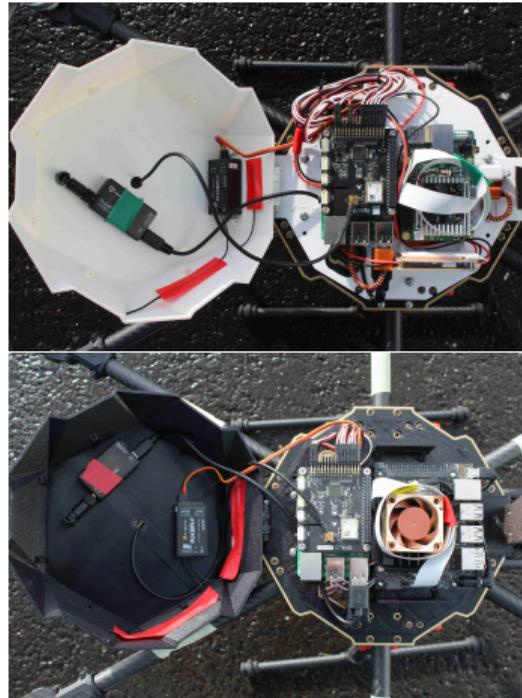
Test Hexacopter Components

- Navio2 + RPi 3 autopilot combo



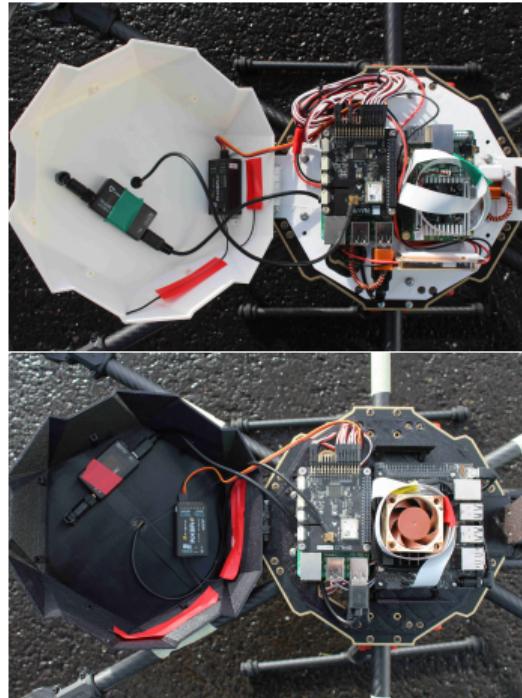
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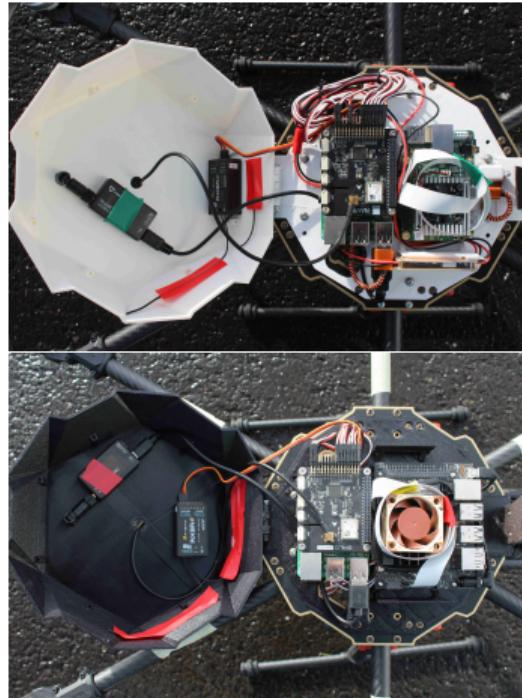
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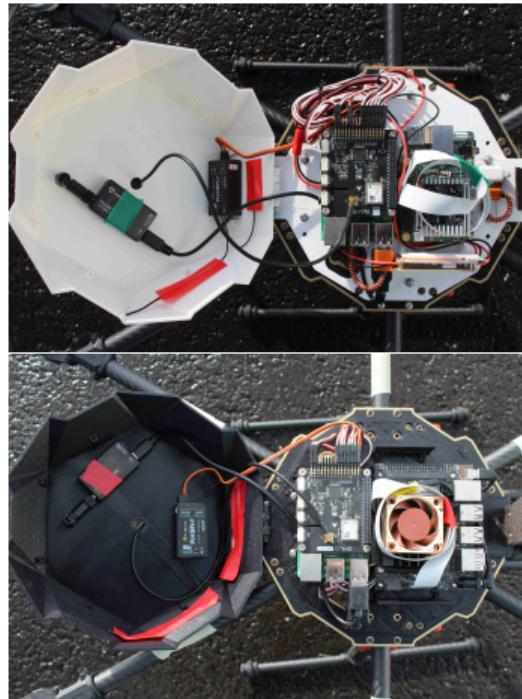
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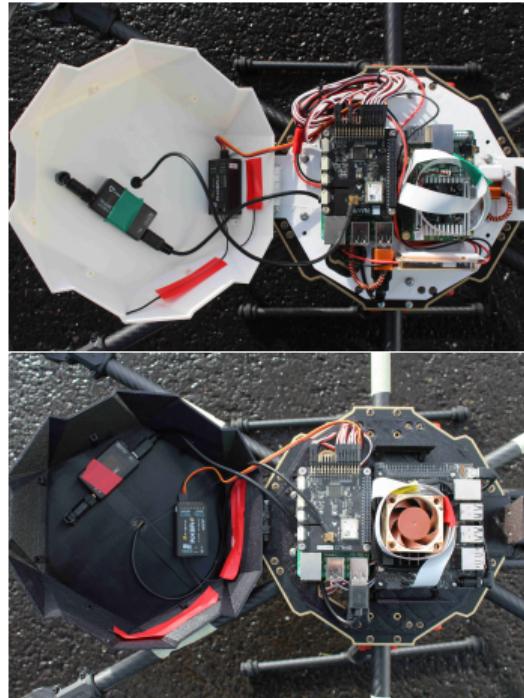
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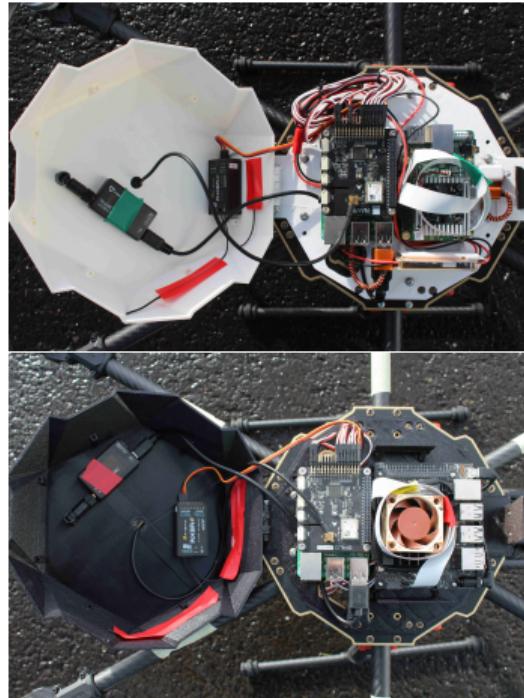
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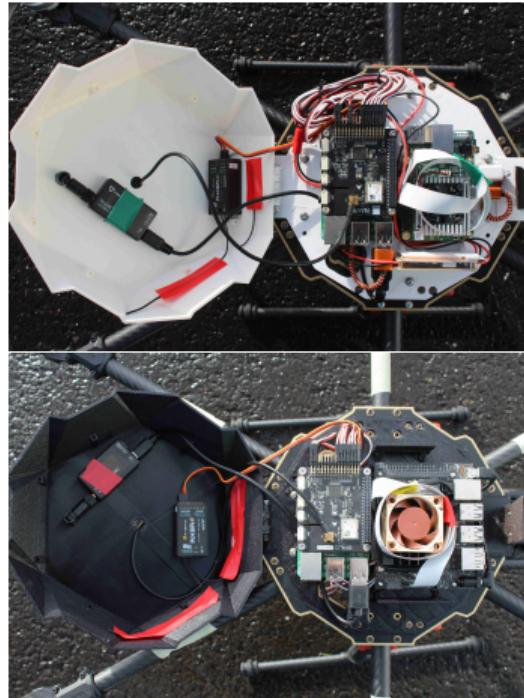
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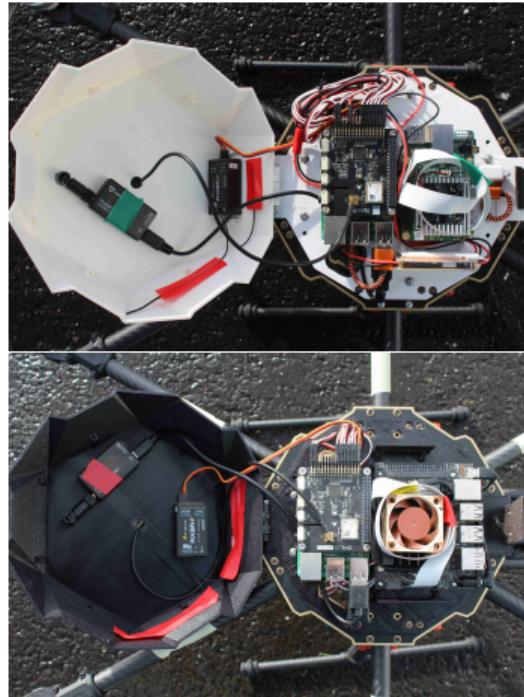
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- Tested Autopilot Softwares
 - ArduPilot



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- Tested Autopilot Softwares
 - ArduPilot
 - PX4 (not technically supported)



Test Hexacopters' Performance

- Stable (manual) flight performance



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- ~20 min flying time



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- Errors during approach
 - Monocular pose estimation ambiguity



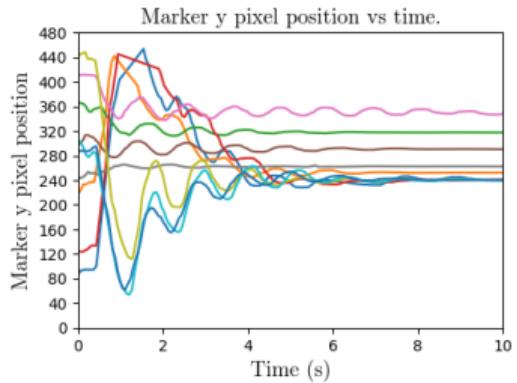
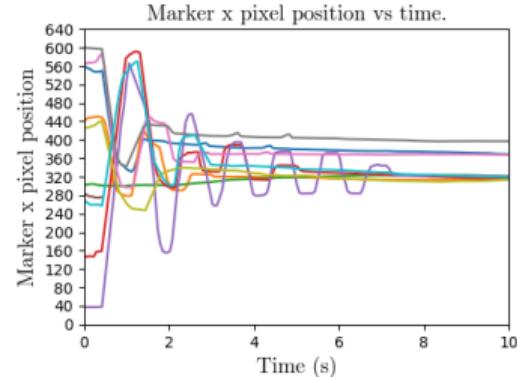
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 - GPS inaccuracy



Test Hexacopters' Performance

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- ~20 min flying time
- Successful marker tracking
- Errors during approach
 - Monocular pose estimation ambiguity
 - GPS inaccuracy
- No successful autonomous landing
(but almost)



Heavy Lift IR Drone

- Project with Christopher Hamilton (geologist, University of Arizona) and Baldur Björnsson



Heavy Lift IR Drone

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- 1.3 m span, 25 kg lift



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Heavy Lift IR Drone

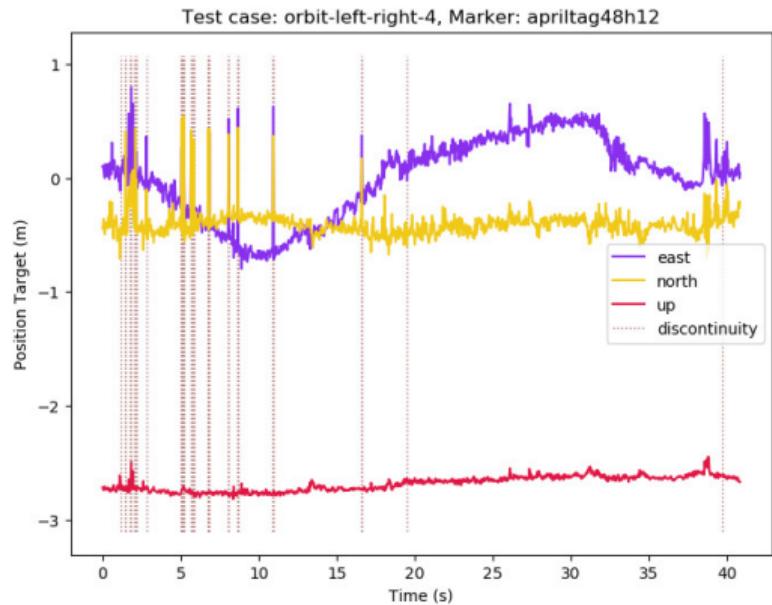
- Project with Christopher Hamilton (geologist, University of Arizona) and Baldur Björnsson
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- Featured on BBC Click



Fiducial System Modifications

Necessary properties:

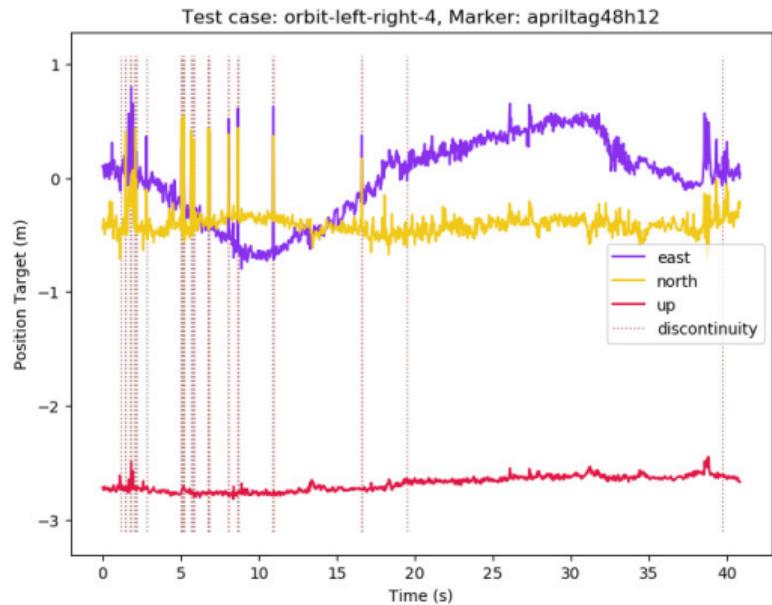
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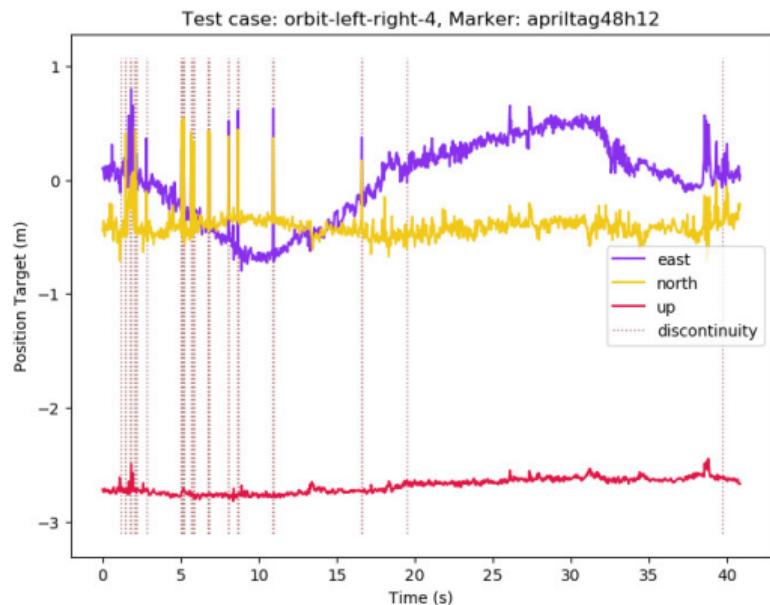
- Mitigates orientation ambiguity
- Detectable at long- and short-range



Fiducial System Modifications

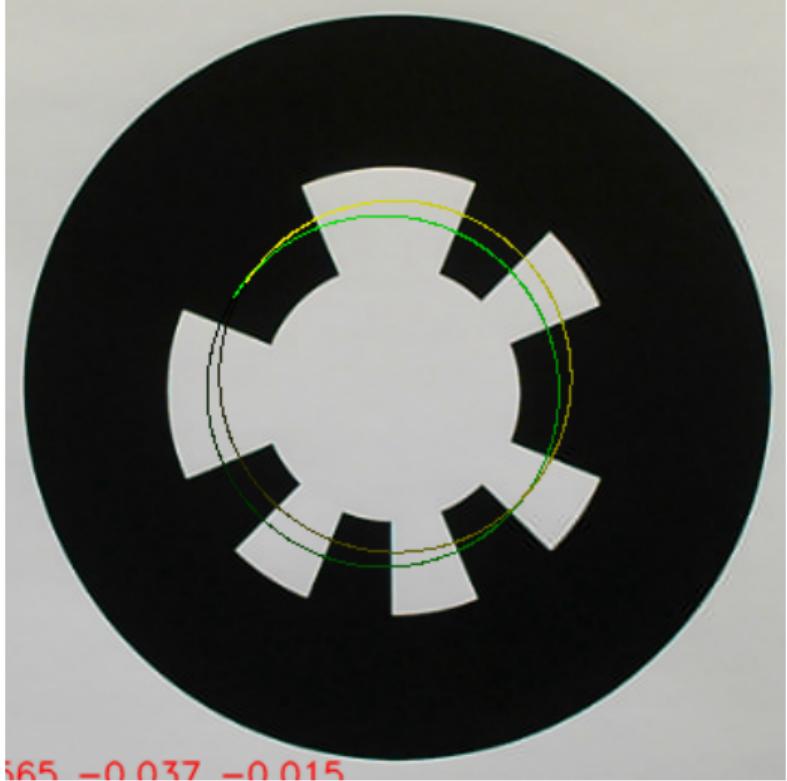
Necessary properties:

- Mitigates orientation ambiguity
- Detectable at long- and short-range
- Runs on embedded hardware



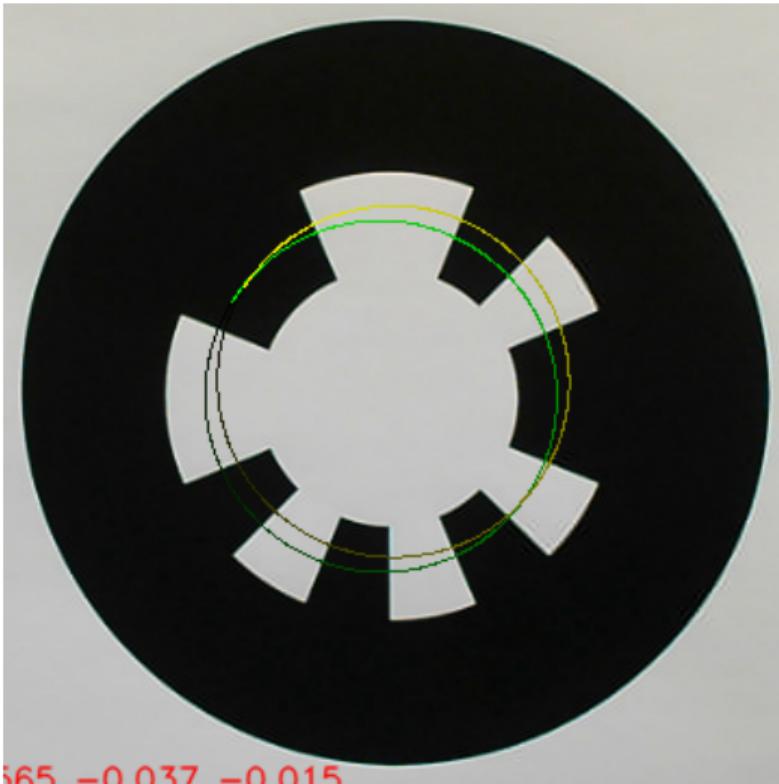
Orientation Ambiguity in WhyCode

- Semi-axes → 2 possible orientations



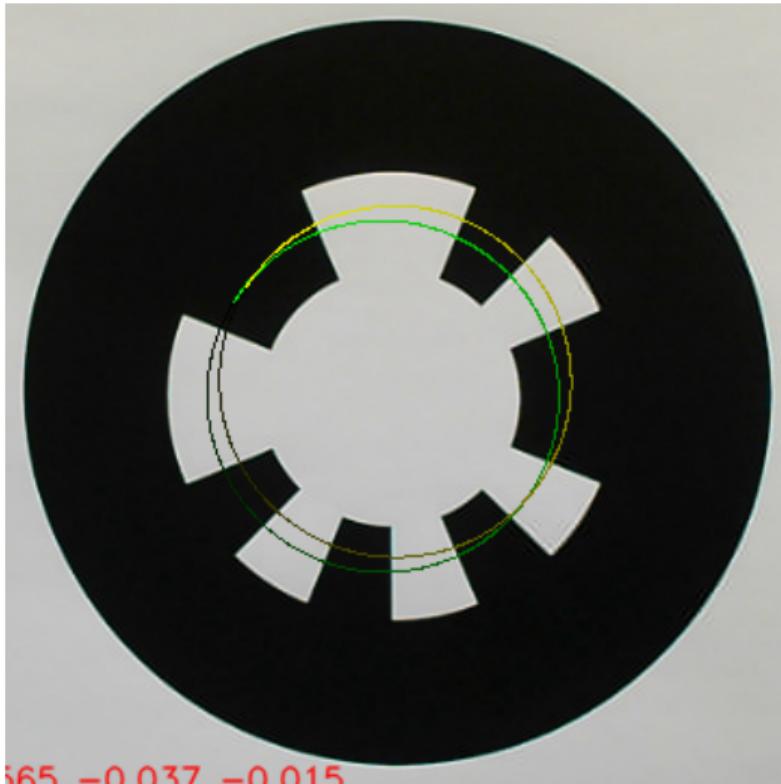
Orientation Ambiguity in WhyCode

- Semi-axes → 2 possible orientations
- Better centered → correct



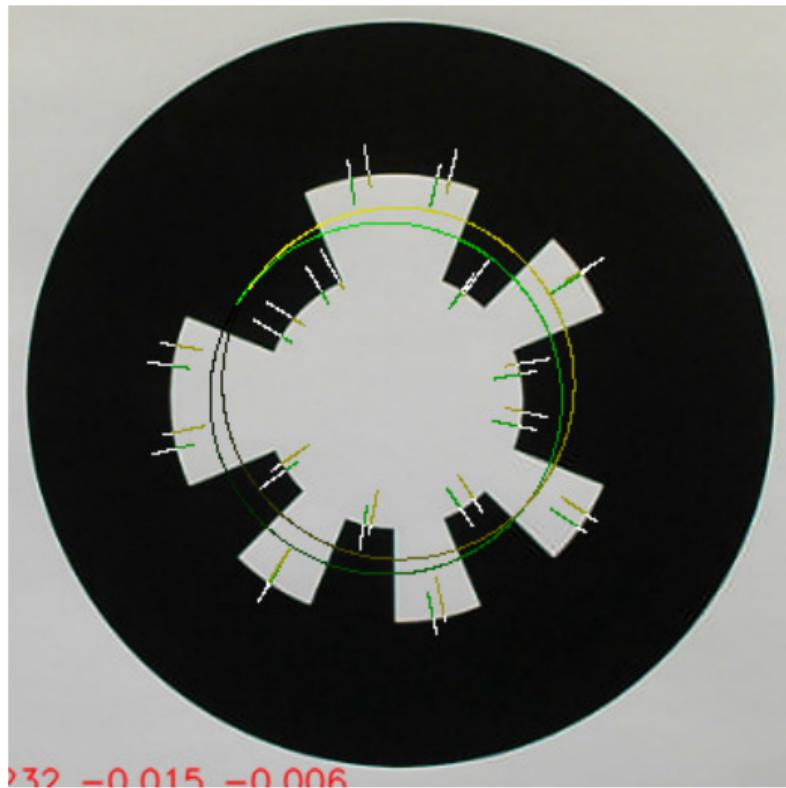
Orientation Ambiguity in WhyCode

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- Better centered → correct
- Arclength of intersections with ID “teeth”



Fiducial System Modifications: “WhyCode Ellipse”

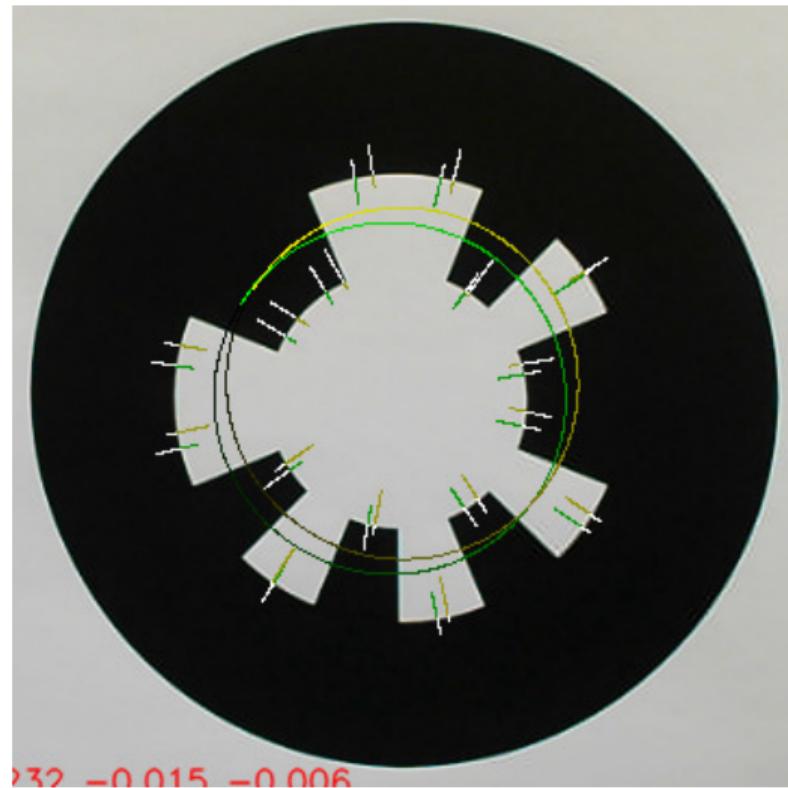
Approach 1: Extra tooth sampling



Fiducial System Modifications: “WhyCode Ellipse”

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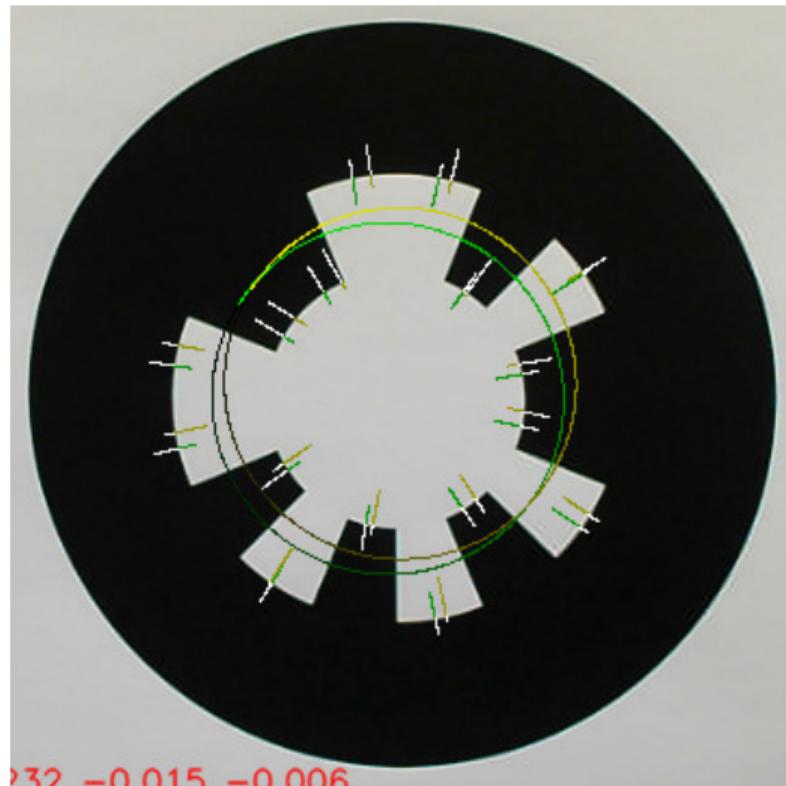
- Sample ID with original method.



Fiducial System Modifications: “WhyCode Ellipse”

Approach 1: Extra tooth sampling

- Sample ID with original method.
- Add: radial sampling on tooth edges.

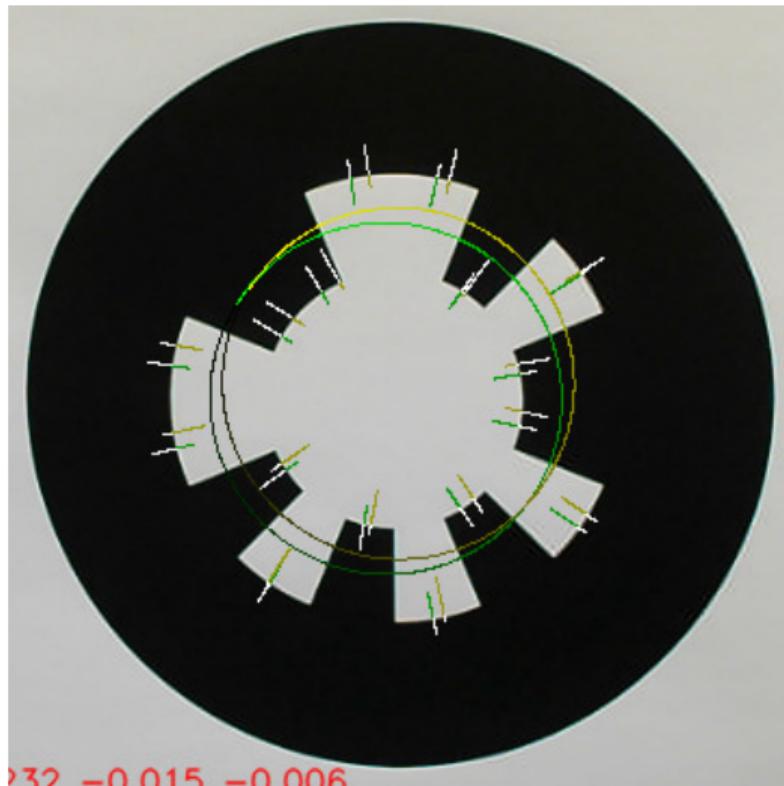


032 -0.015 -0.006

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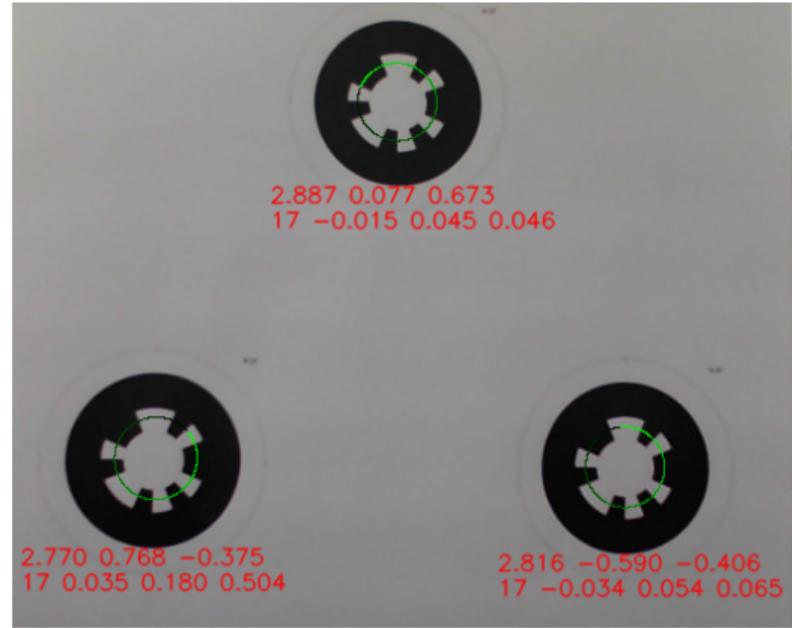
Approach 1: Extra tooth sampling

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- Choose solution based on tooth edge predictions.



Fiducial System Modifications: “WhyCode Multi”

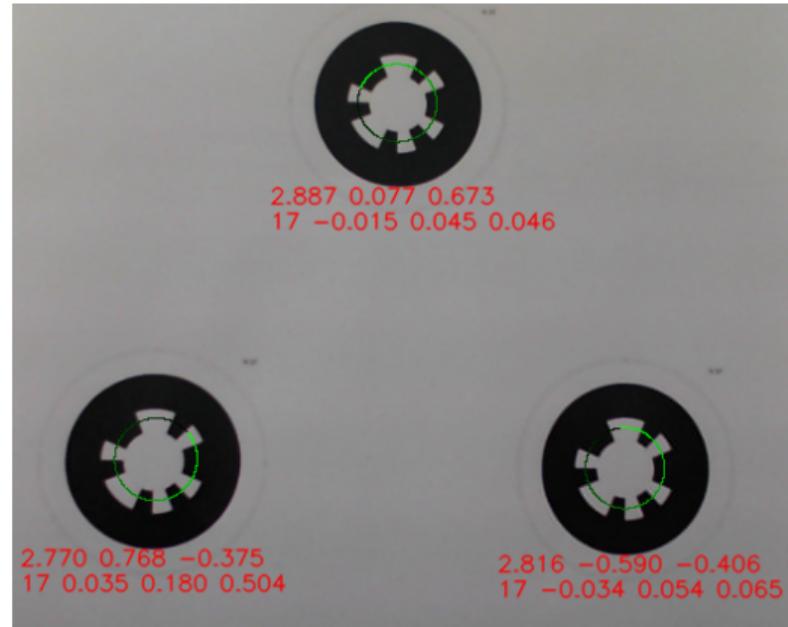
Approach 2: Coplanar marker arrangements



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Approach 2: Coplanar marker arrangements

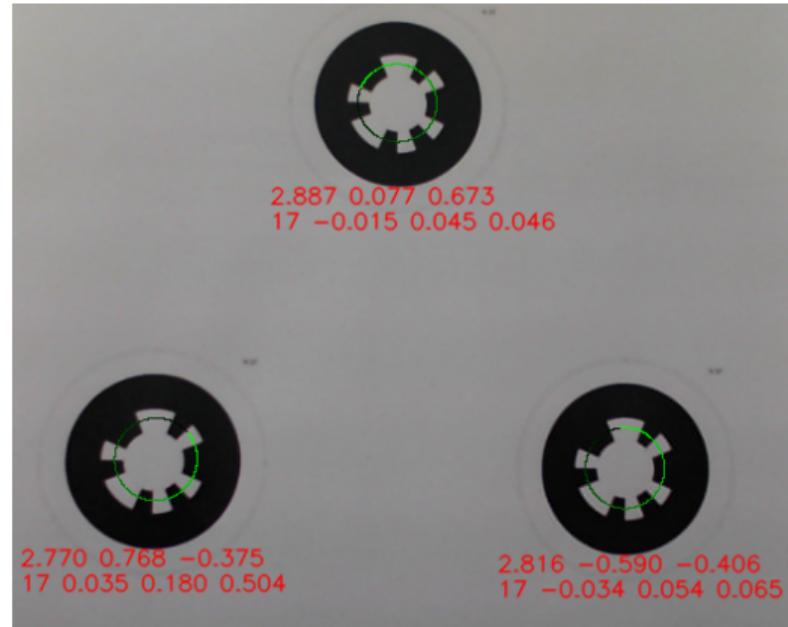
- Ignore individual marker orientations



Fiducial System Modifications: “WhyCode Multi”

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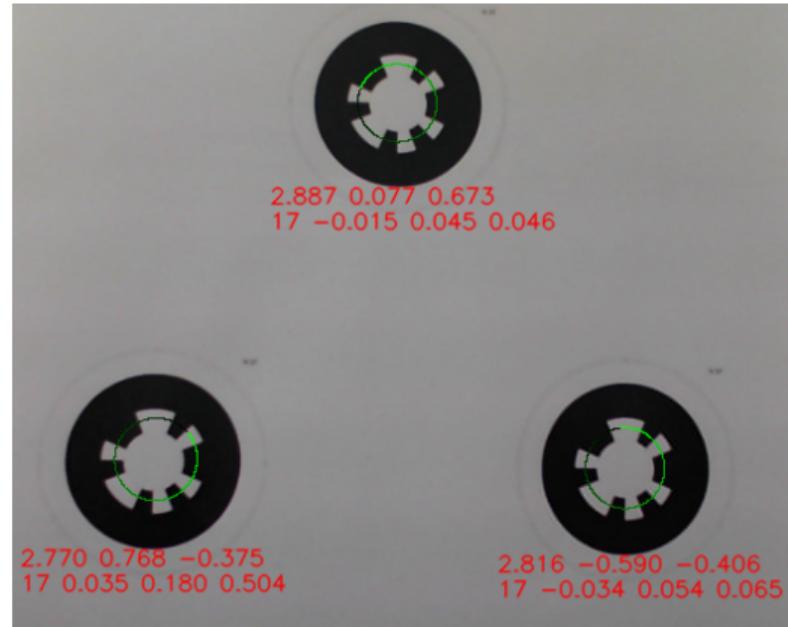
- Ignore individual marker orientations
- Calculate normal vector to the plane connecting the markers.



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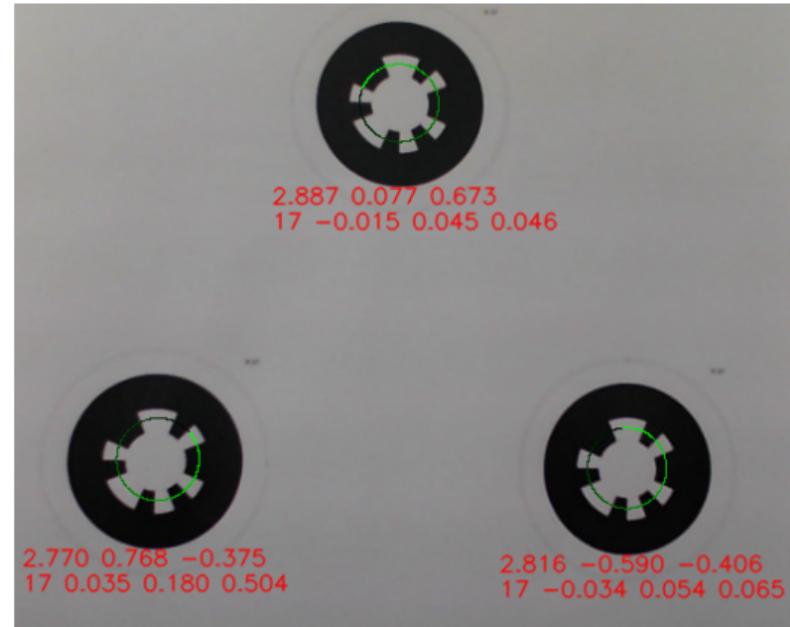
- Ignore individual marker orientations
- Calculate normal vector to the plane connecting the markers.
- Extract pitch and roll from the normal vector.



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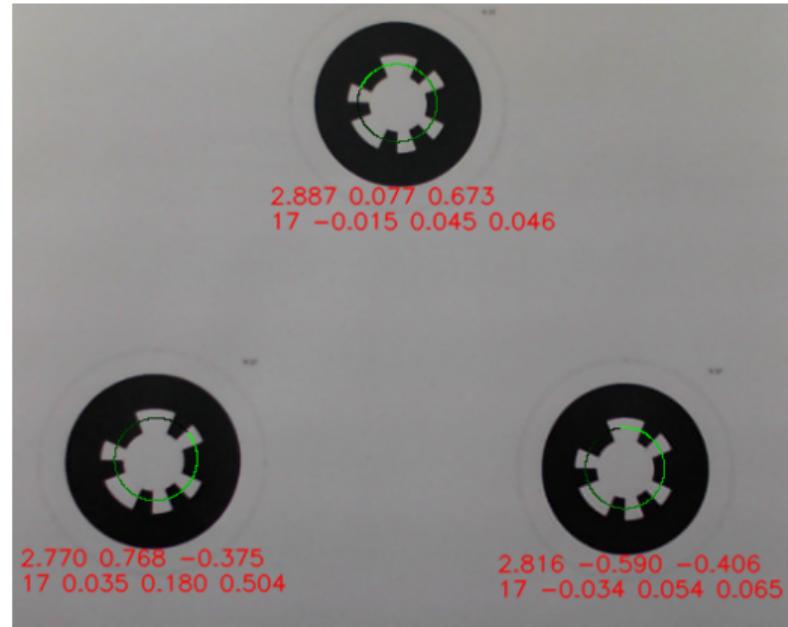
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Approach 2: Coplanar marker arrangements

- Ignore individual marker orientations
- Calculate normal vector to the plane connecting the markers.
- Extract pitch and roll from the normal vector.
- Extract yaw from the marker IDs.
- Takes advantage of WhyCode’s efficiency.



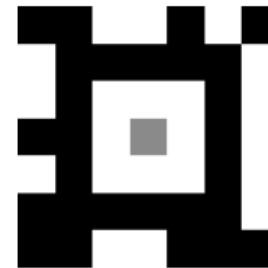
Fiducial System Modifications: April Tag

April Tag: less orientation ambiguity, but less computationally efficient.

April Tag 48h12: more sophisticated, “recursive.”

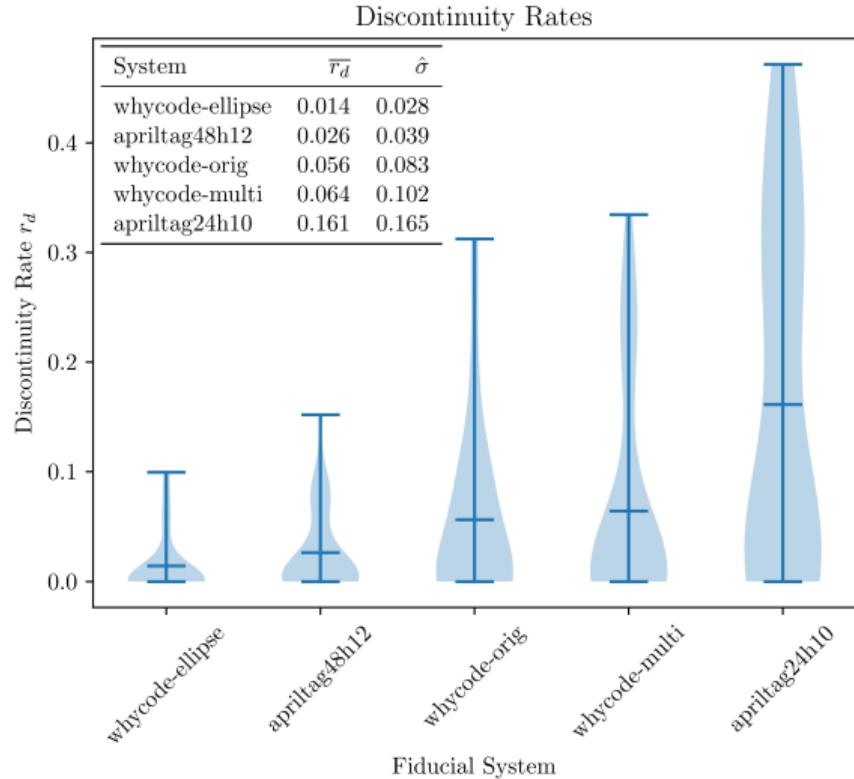


April Tag Custom 24h10: “recursive,” smaller definition



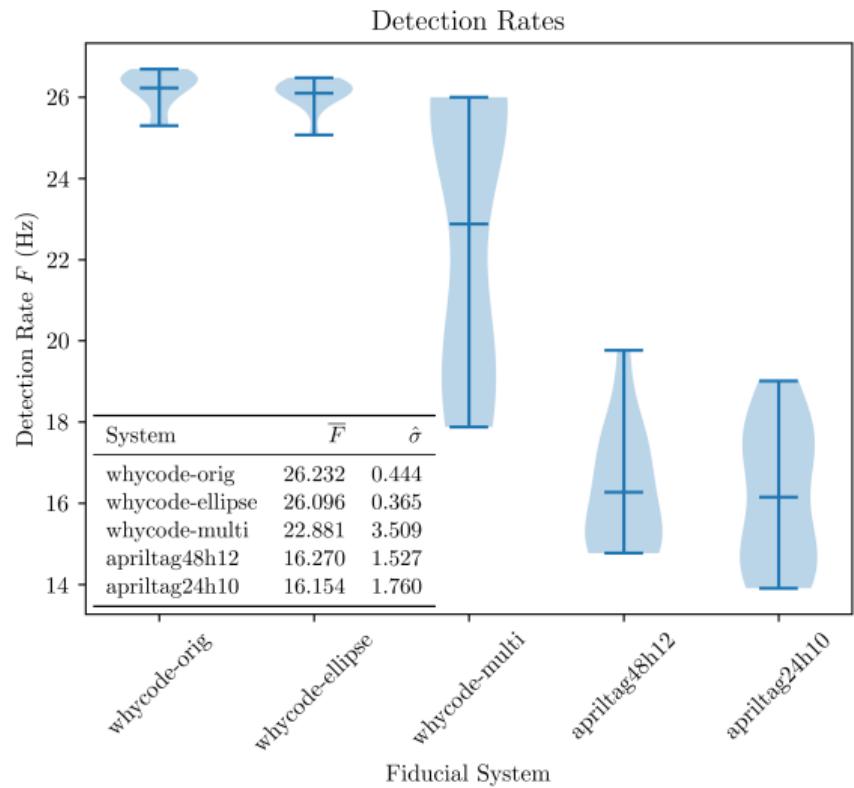
Performance Analysis: Discontinuity Rates

- Orientation ambiguity → discontinuities.
- Discontinuity rate \bar{r}_d is the number of discontinuities per detection.
- Lower is better.



Performance Analysis: Detection Rates

- Detection rate \bar{F} is the number of detections per second.
- Tested on Raspberry Pi 4.
- Higher is better.



Autonomous Landing Proof of Concept

- Indoor experiments with DJI Spark



(Banana for scale.)

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 - Reduces logistical considerations: transportation, weather



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- Indoor experiments with DJI Spark
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- Requires DJI Mobile SDK, Custom Android App, and **lots** of workarounds.



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- Video frames are offloaded (via WiFi) to Raspberry Pi 4 for processing



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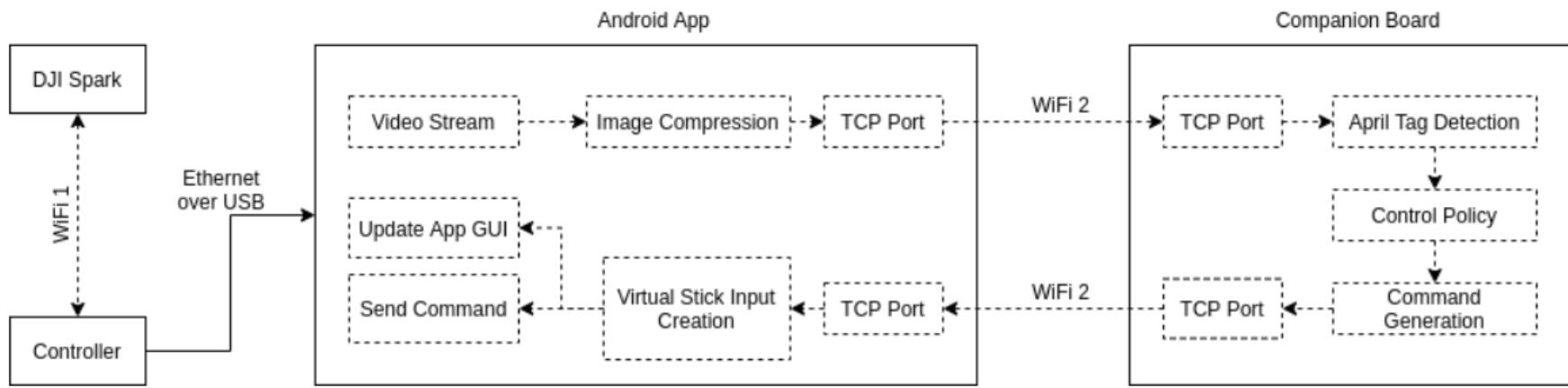
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- Limiting factor: pre-transmission image compression on tablet (6-7 Hz)

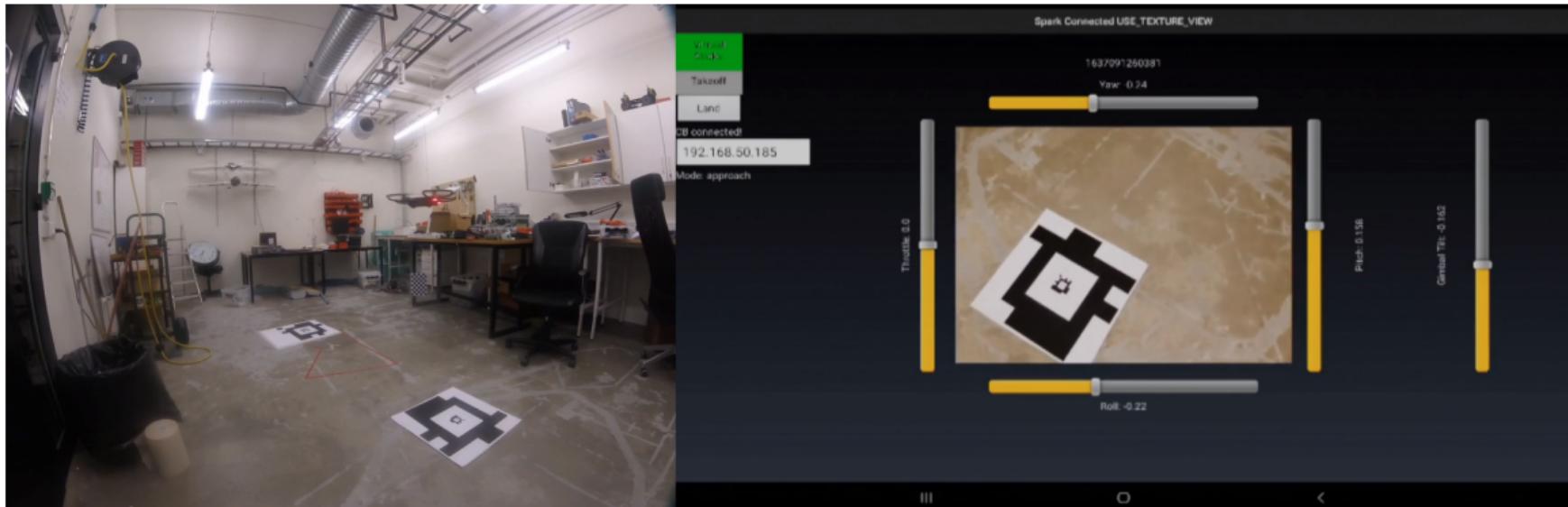


(Banana for scale.)

Autonomous Landing Proof of Concept: System Architecture



Demo with worst-performing April Tag 24h10!



Publications

- Submitted: Evaluation of April Tag and WhyCode Fiducial Systems for Autonomous Precision Drone Landing with a Gimbal-Mounted Camera
- In Progress: results from autonomous landing proof of concept



Research Plan



Overview: Unstructured Autonomous Landing

- Focus on terrain analysis



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 - Topographical analysis



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 - terrain type classification: (snow, ice, water, grass, rock, etc.)



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- Focus on real time performance



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 - Process (quickly): ??
 - Output: safe landing sites (e.g. heat map)



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 - Process (quickly): ??
 - Output: safe landing sites (e.g. heat map) → flight control commands



Data Set Generation

AirSim: realistic simulator

- Automatic generation of large data sets

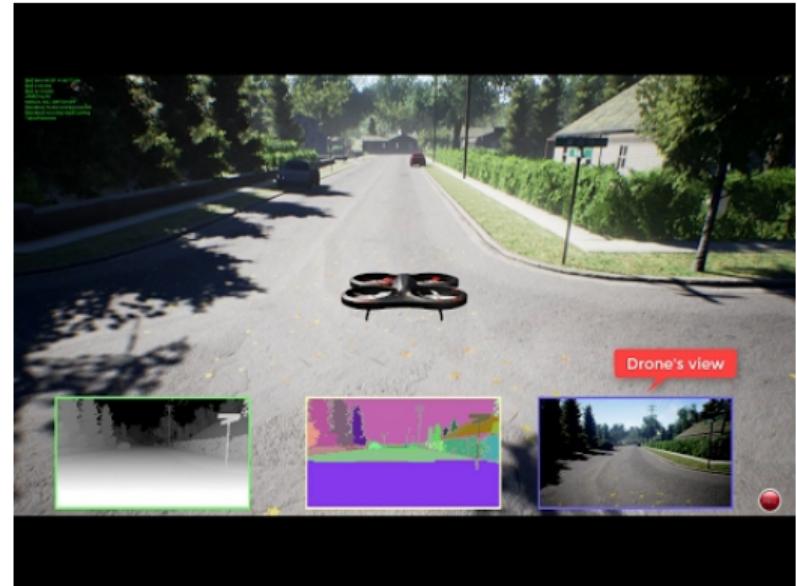


Image source



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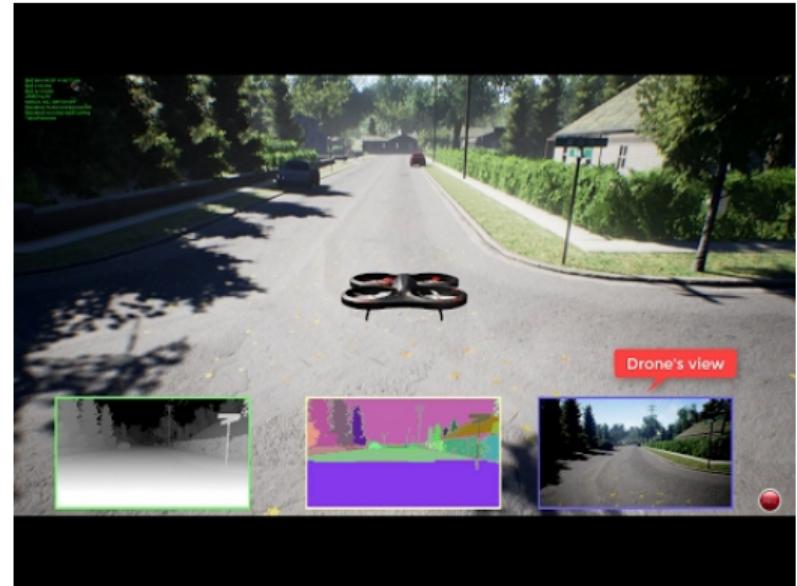


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- Synthetic sensor data (LIDAR, RGBD cameras)
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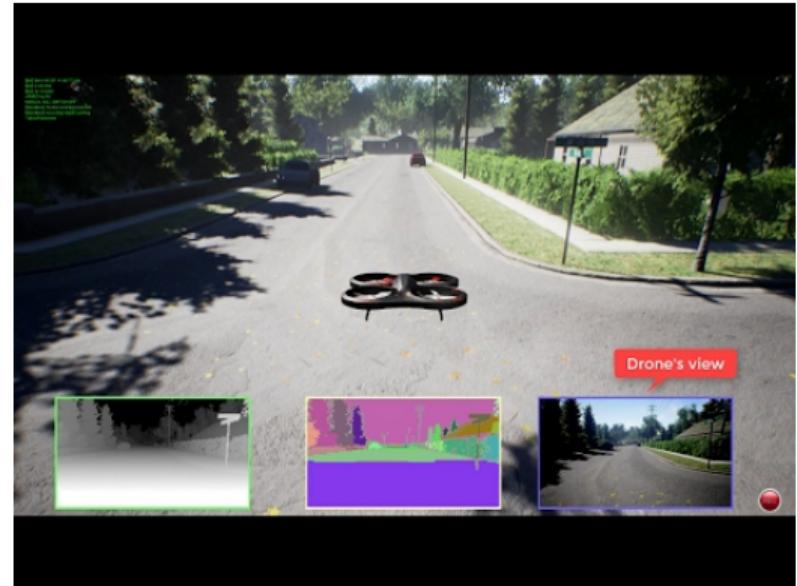


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 - LIDAR → RADAR

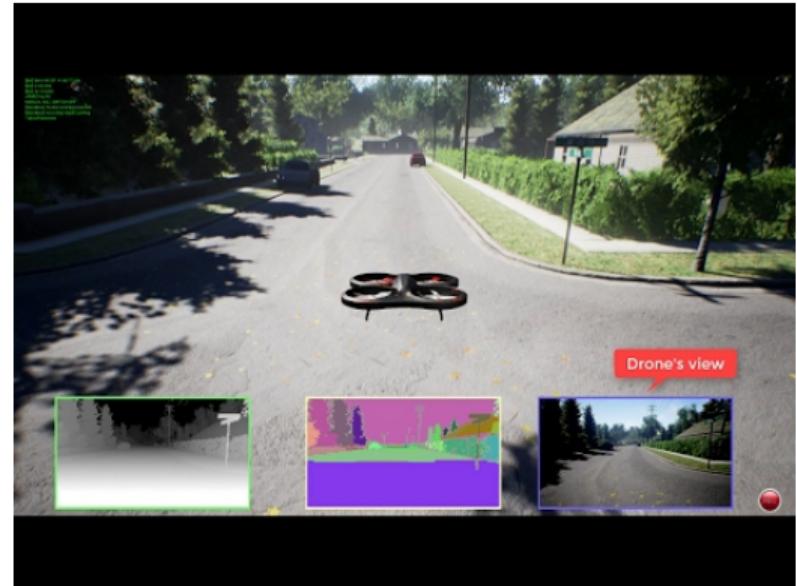


Image source



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- Specify realistic sensor parameters

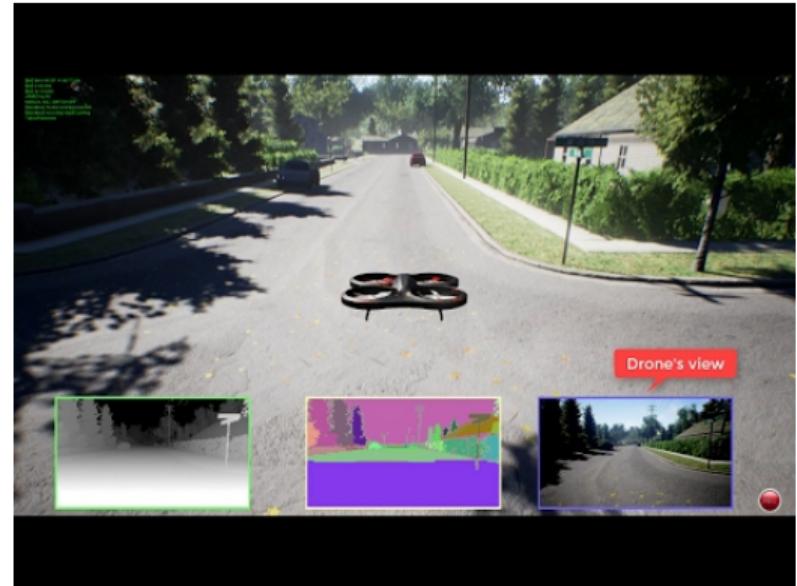


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- Specify realistic sensor parameters
- Segmentation masks for high-level label generation

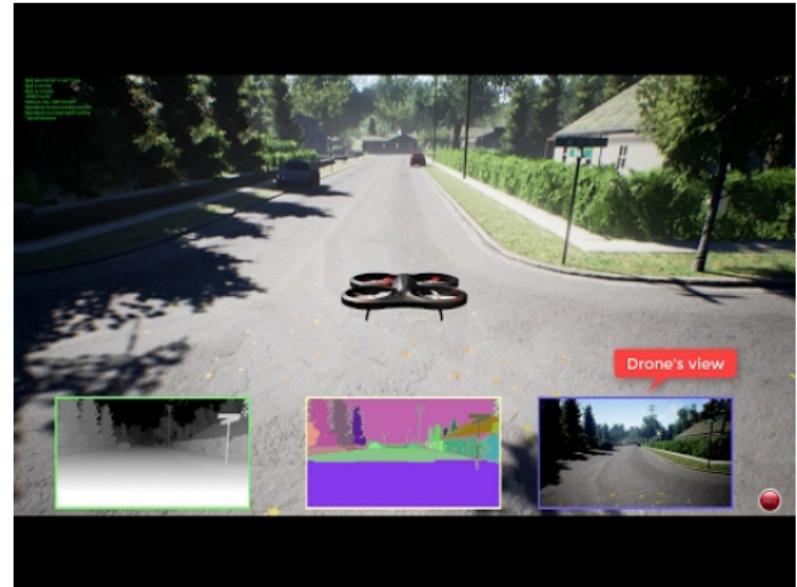


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- Tag with IMU data
 - LIDAR → RADAR
- Specify realistic sensor parameters
- Segmentation masks for high-level label generation
- Labeling method can be slow, hand-tuned

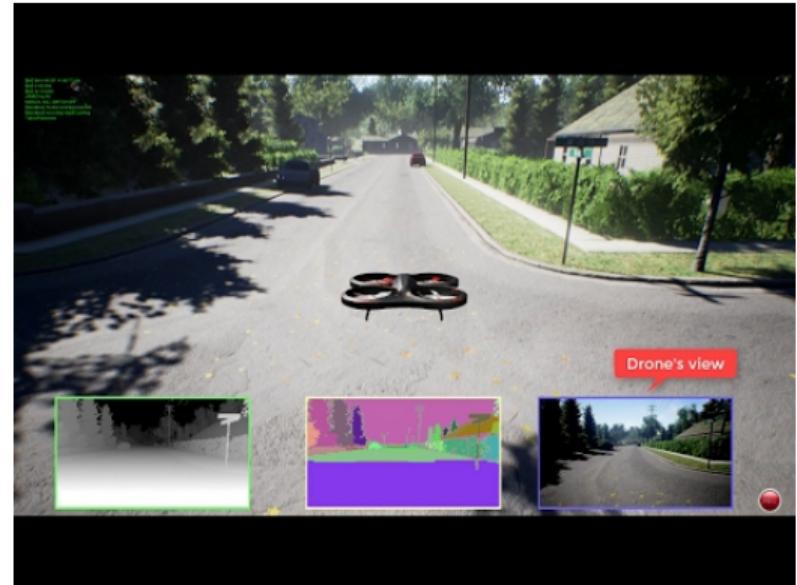


Image source



Terrain Classifier Creation

- Test several methods



Terrain Classifier Creation

- Test several methods
 - Conventional signal/image processing



Terrain Classifier Creation

- Test several methods
 - Conventional signal/image processing
 - Deep learning methods



Terrain Classifier Creation

- Test several methods
 - Conventional signal/image processing
 - Deep learning methods
 - Combination



Terrain Classifier Creation

- Test several methods
 - Conventional signal/image processing
 - Deep learning methods
 - Combination
- Pre-processing wrappers:
 - Rectification/calibration



Terrain Classifier Creation

- Test several methods
 - Conventional signal/image processing
 - Deep learning methods
 - Combination
- Pre-processing wrappers:
 - Rectification/calibration
 - Downsampling/resizing



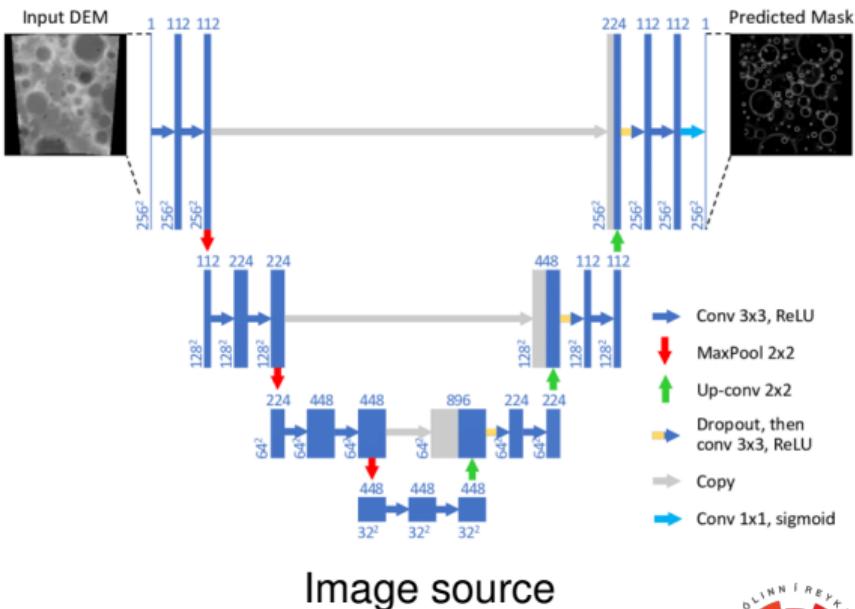
Terrain Classifier Creation

- Test several methods
 - Conventional signal/image processing
 - Deep learning methods
 - Combination
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Simulation is not enough!



Testing in the Real World

- Offline
 - Accuracy on real world data

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Drone Upgrades

- New flight controller: Pixhawk Cube Orange



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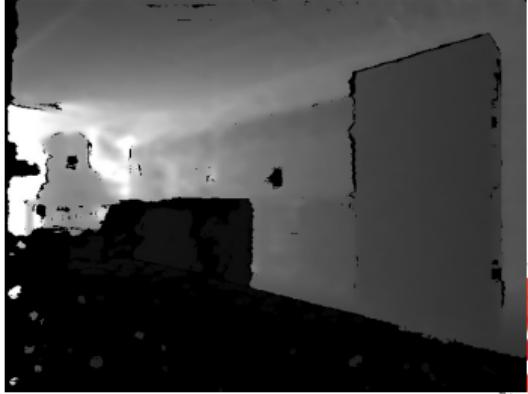
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 - Intel RealSense D455 RGBD camera (IMU)
 - Intel RealSense L515 LIDAR (IMU)
 - Texas Instruments IWR6843 60 GHz RADAR



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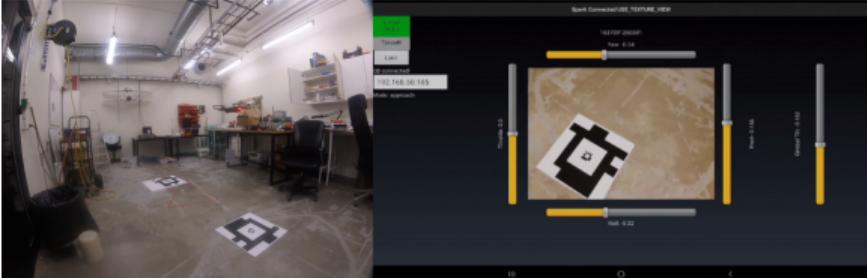
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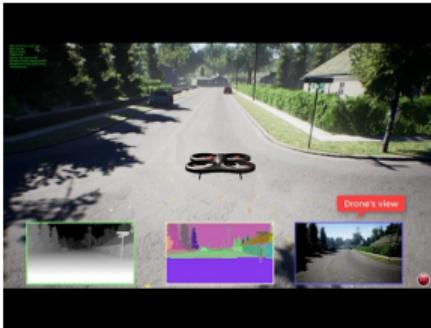


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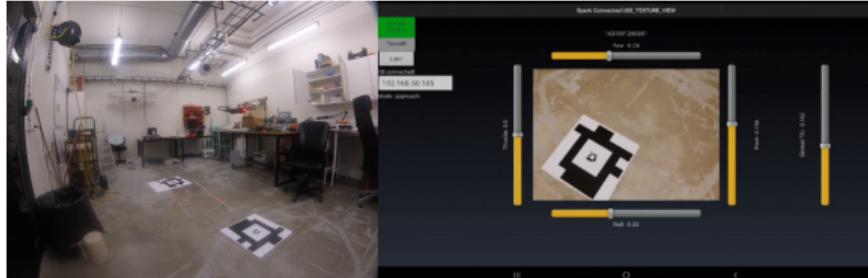


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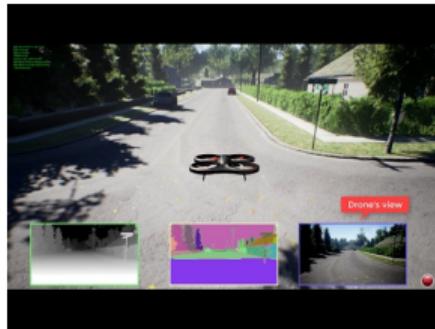


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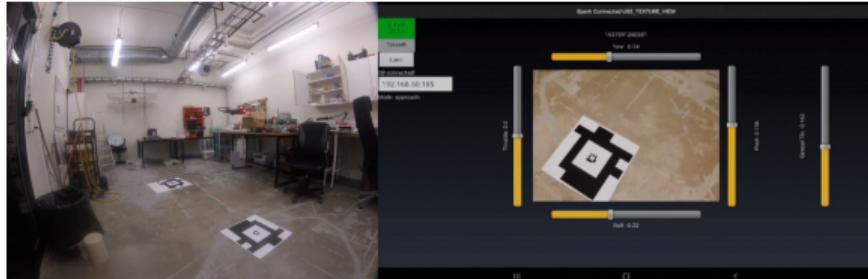


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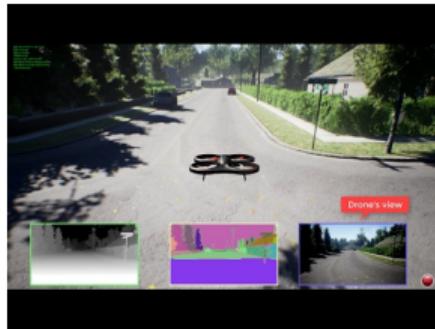


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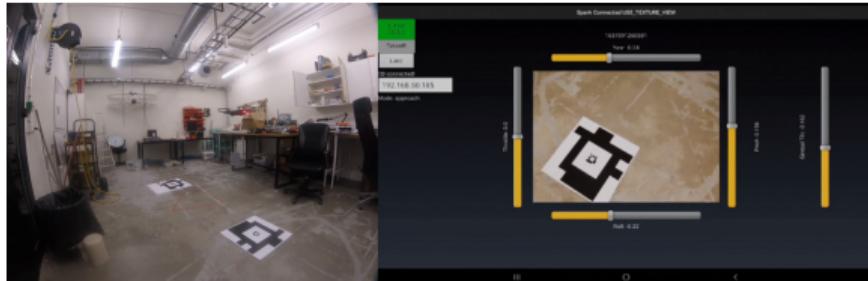


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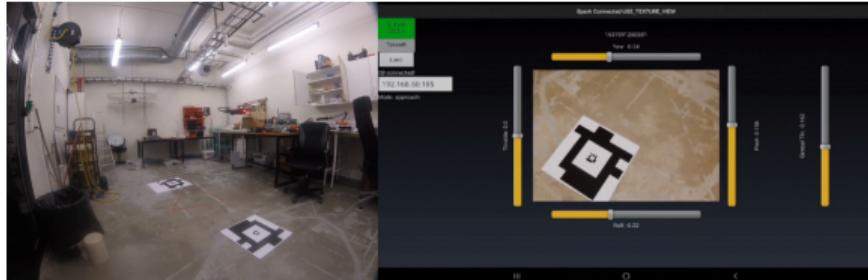


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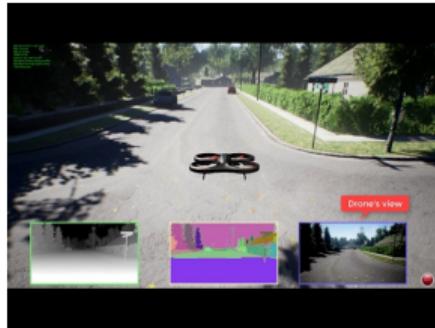


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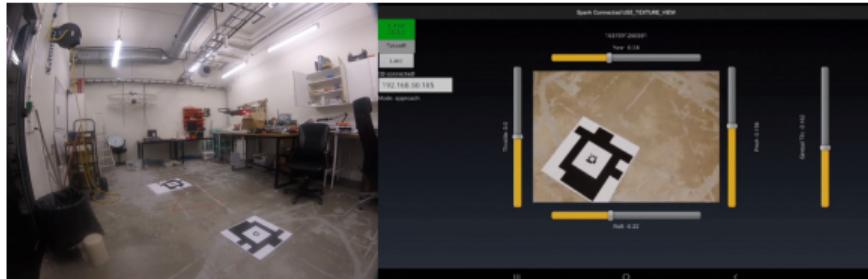


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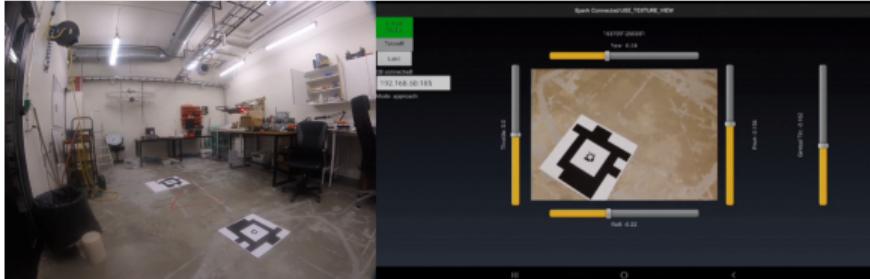


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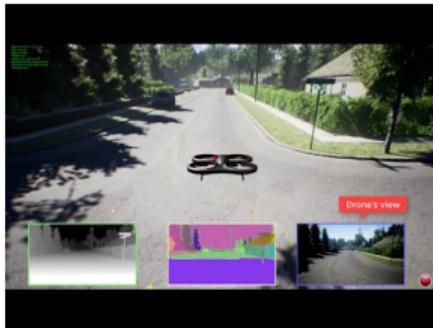


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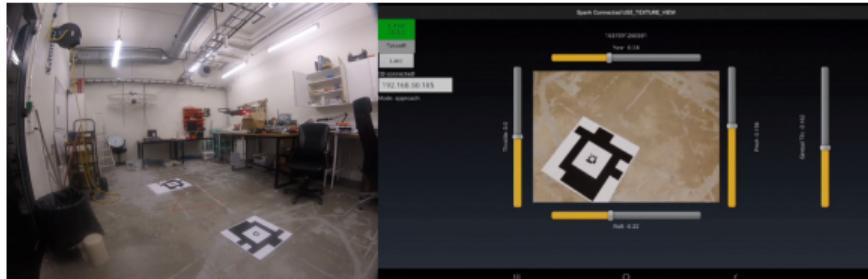


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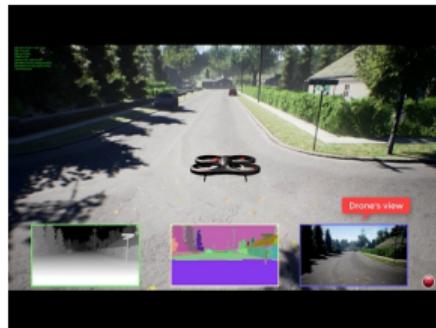


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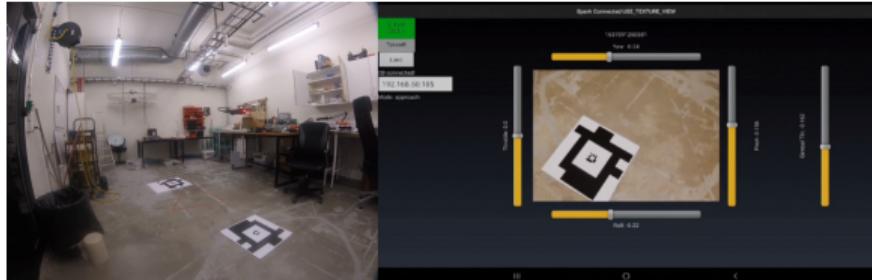


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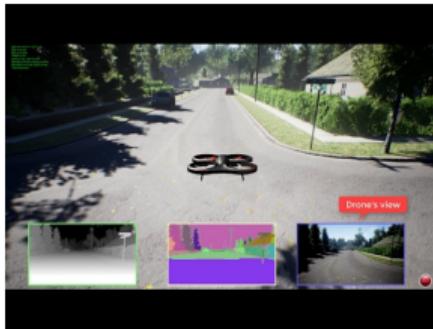


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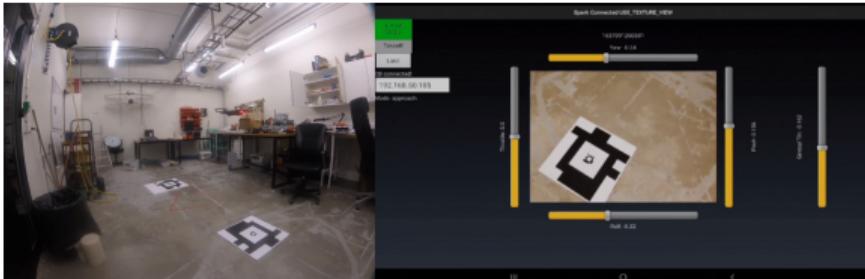


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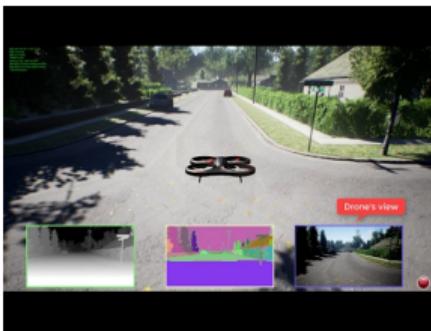


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- Thank you! Are there any questions?



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References

