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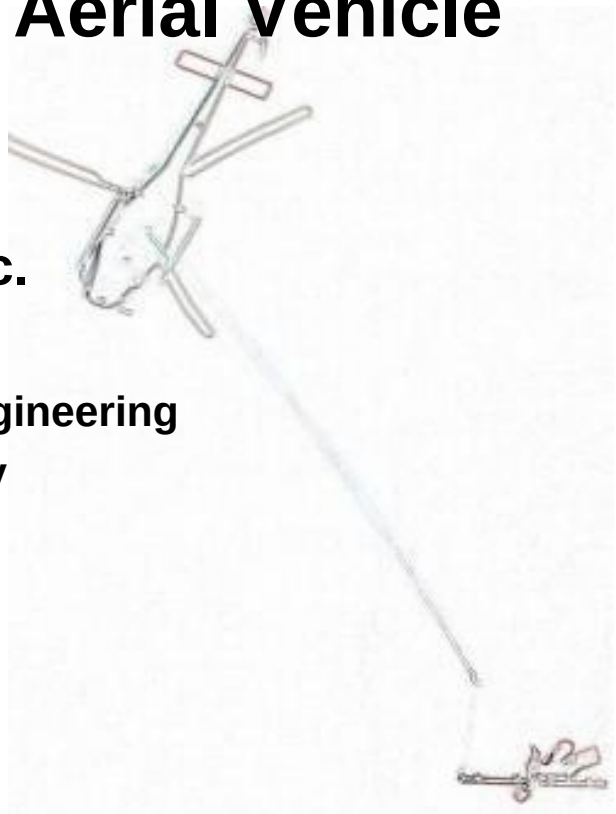
Obstacle Detection Using Monocular Camera for Low Flying Unmanned Aerial Vehicle



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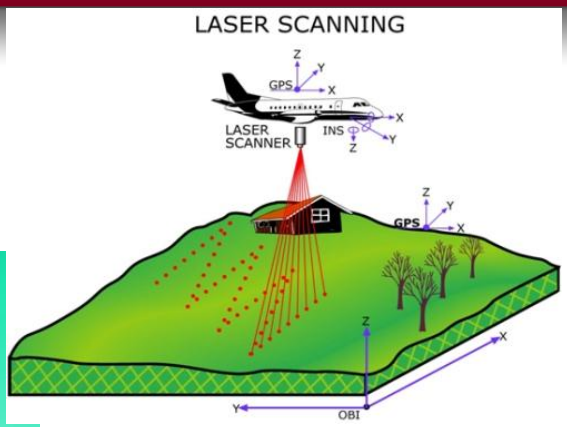
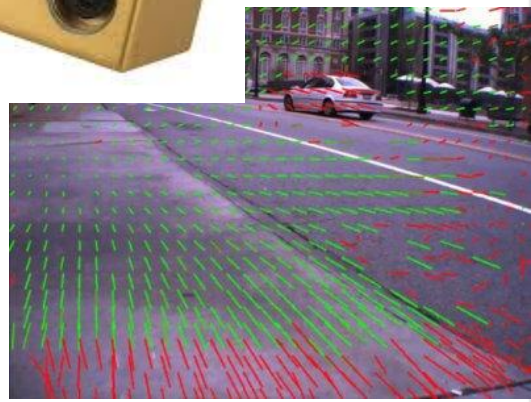
Systems and Computer Engineering
Carleton University
January 2015

Introduction

- **Bearing and Range Sensors**
  - Radar, Lidar, Sonar
    - *Require Scanning*
  - 3D Flash Lidar



- **Bearing Only Sensor**
  - Camera
    - *Binocular Configuration*
    - *Monocular Configuration*



- **Computer Algorithm**
  - Machine Vision
  - Simultaneous Localization and Mapping (SLAM)

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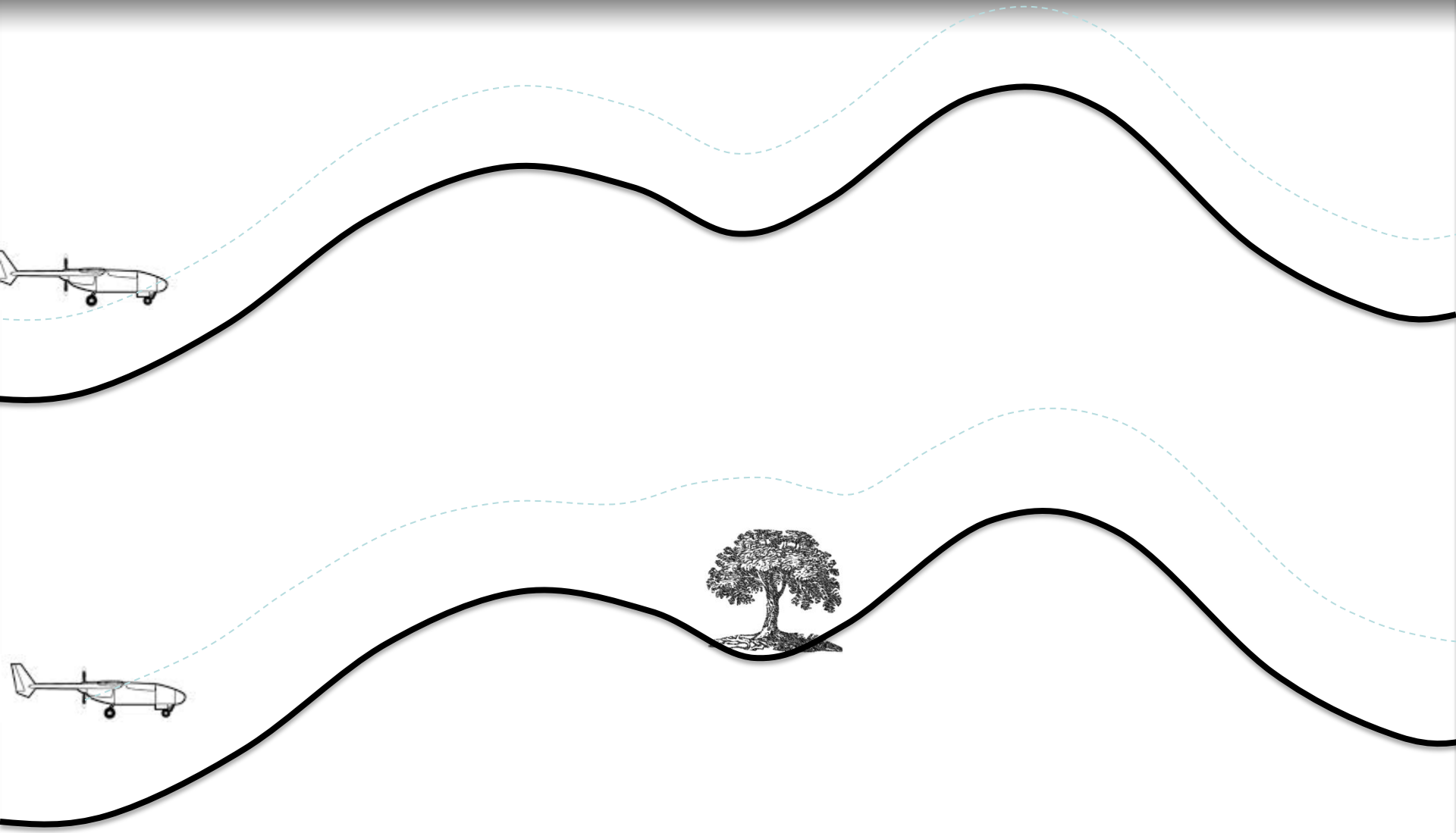
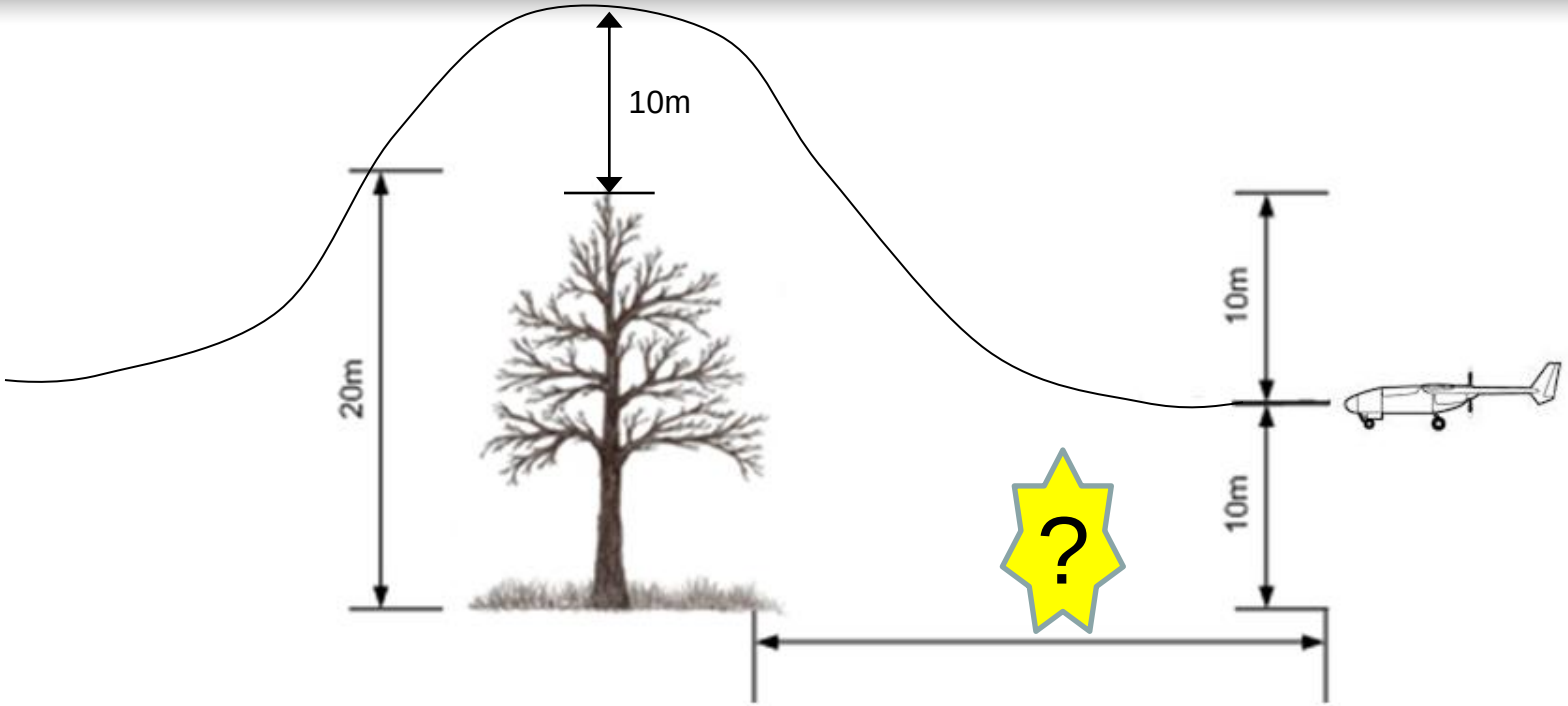
Problem Statement



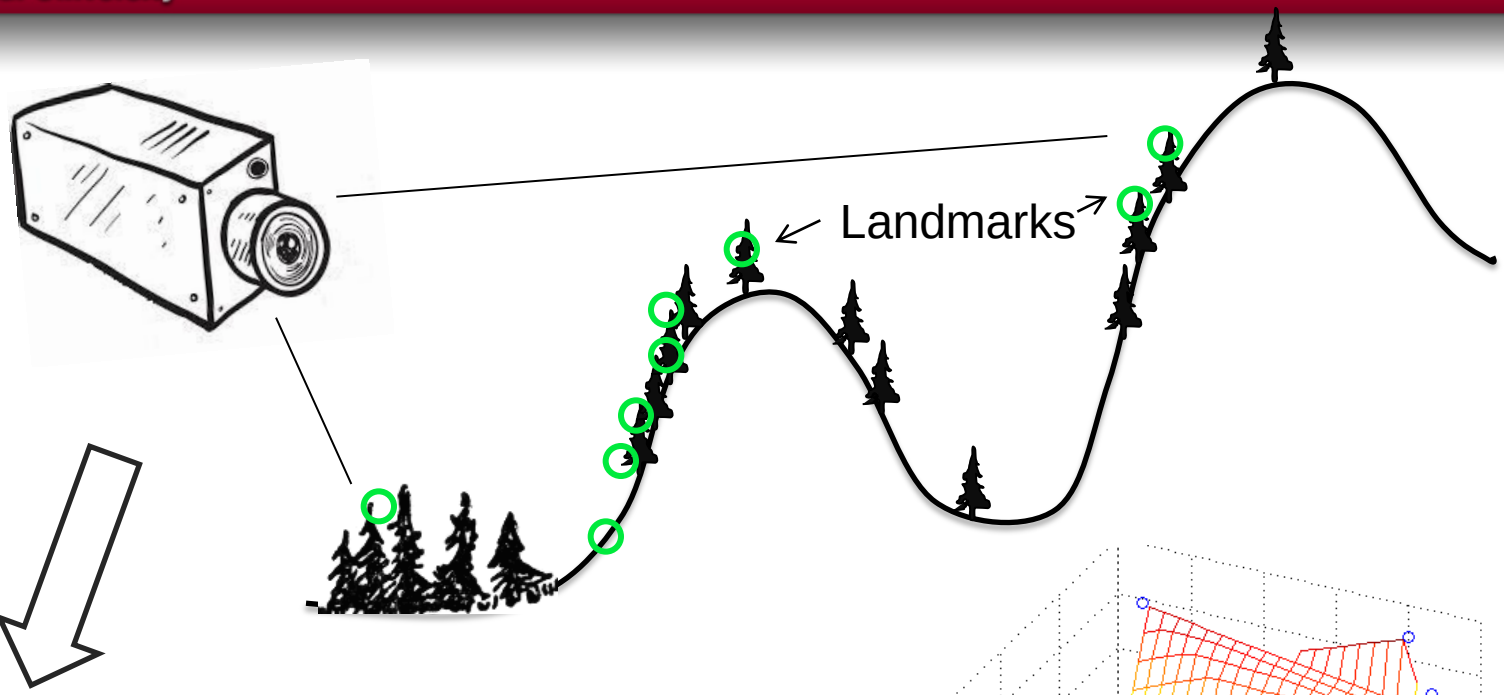
Problem Statement

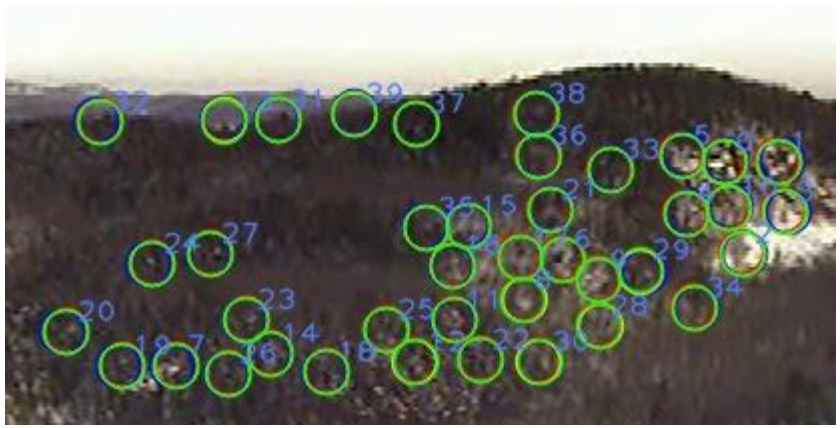


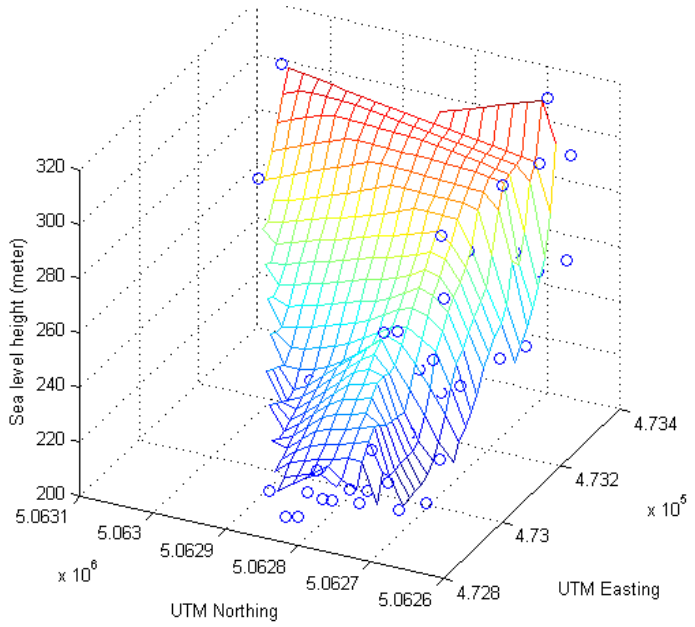
UAV Vertical Rise: 122 meters per minute
Clearance: 10 meters

303.64 meters or further @ 60 knots (30.87m/s)
505.97 meters or further @ 100 knots (51.44m/s)

Problem Statement





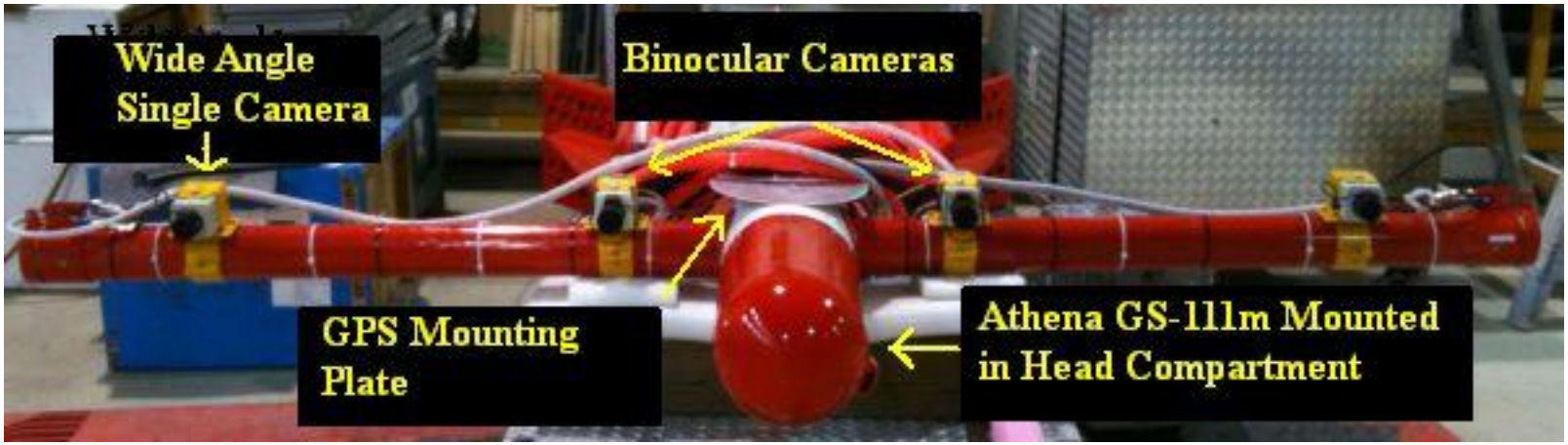


Contribution 1:
Real Aerial Video and Data Collection

SUAS Take Off

Contribution 1:
Real Aerial Video and Data Collection

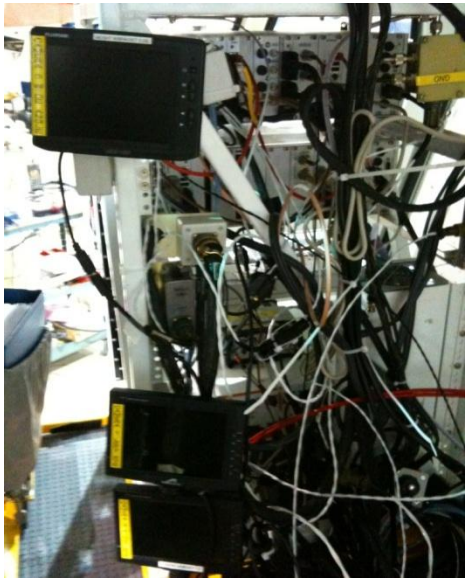
Sensors and Data Acquisition Equipment



GS-111M

GPS Antenna

CDAC



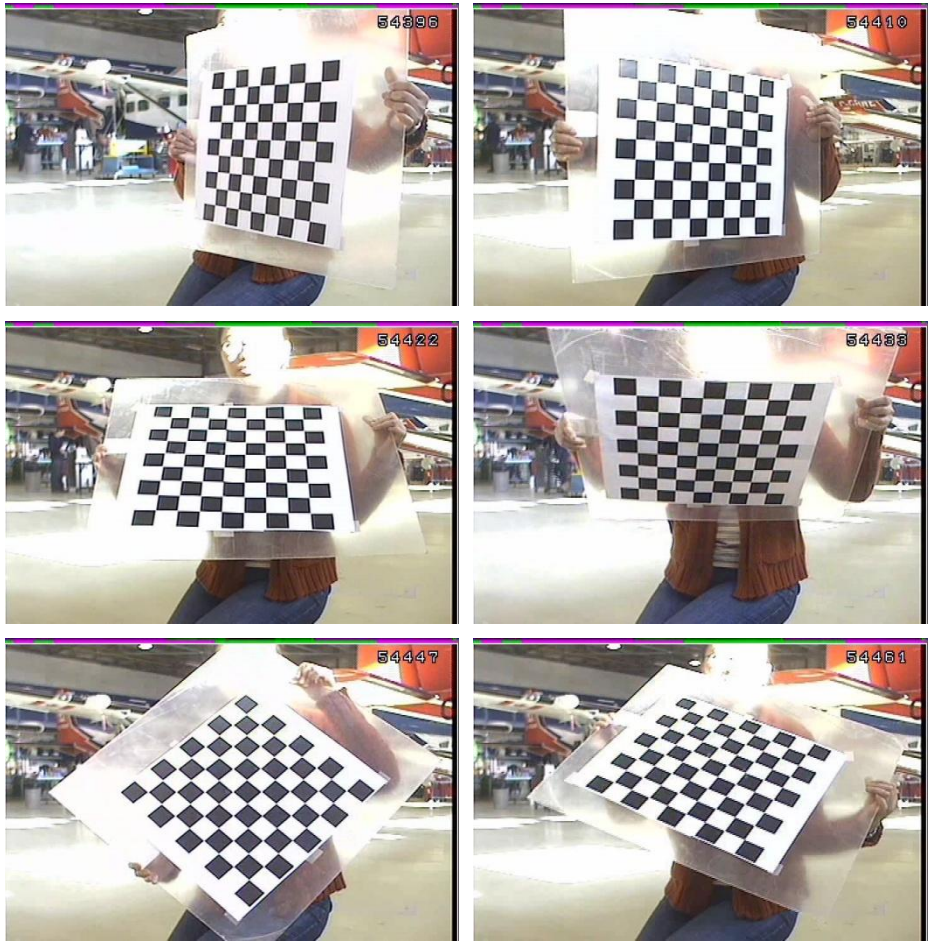
Contribution 1:
Real Aerial Video and Data Collection

Aerial Video Footage

Contribution 1:
Real Aerial Video and Data Collection

Camera Calibration

Parameter	Result
f_x	887.6 pixels
f_y	805.7 pixels
c_x	381.8 pixels
c_y	293.7 pixels
k_1	-0.102
k_2	-0.535
p_1	1.15e-003
p_2	8.40e-003



Contribution 2: CC-EKF-SLAM

Monocular Image Sequence

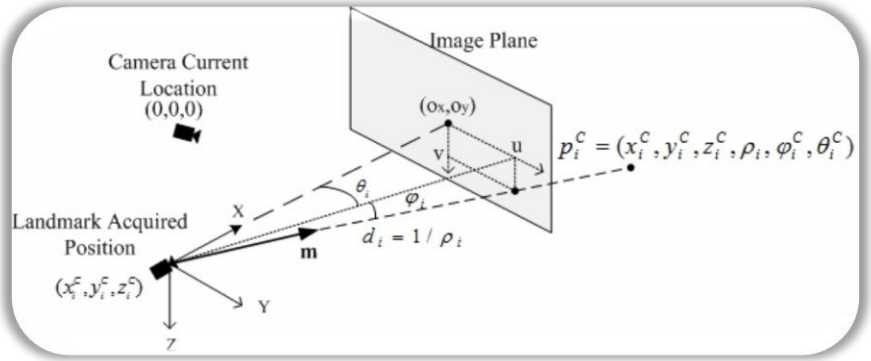
Camera Centric EKF based SLAM

UAV Trajectory

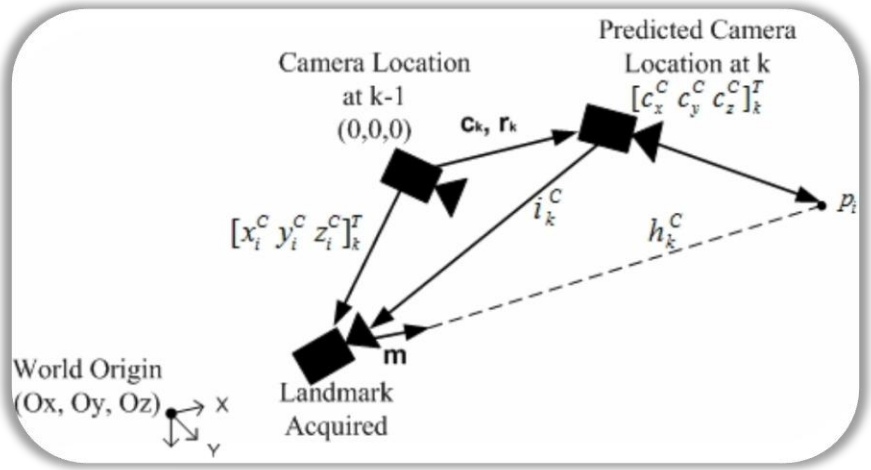
Sparse Terrain Map

Velocity, Acceleration
Roll, Pitch, Heading

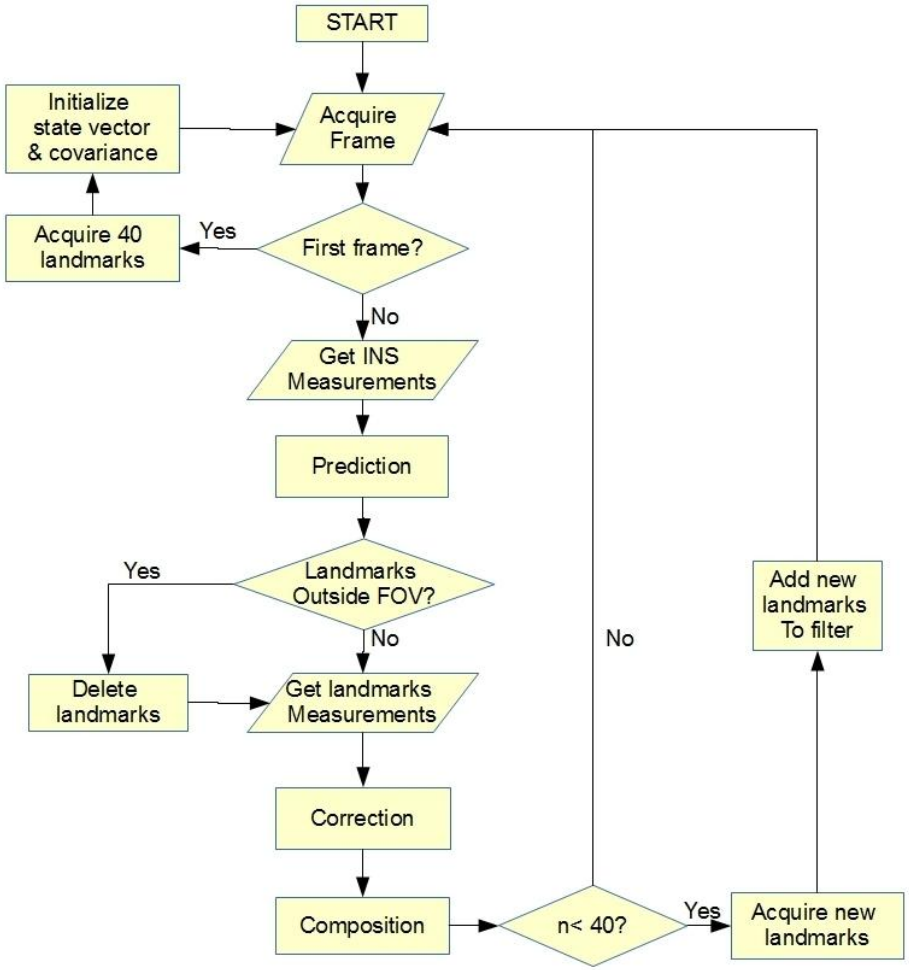
Contribution 2: CC-EKF-SLAM



Inverse Depth Parameterization



Camera Centric Coordinate System



* n = number of landmarks currently tracked by filter

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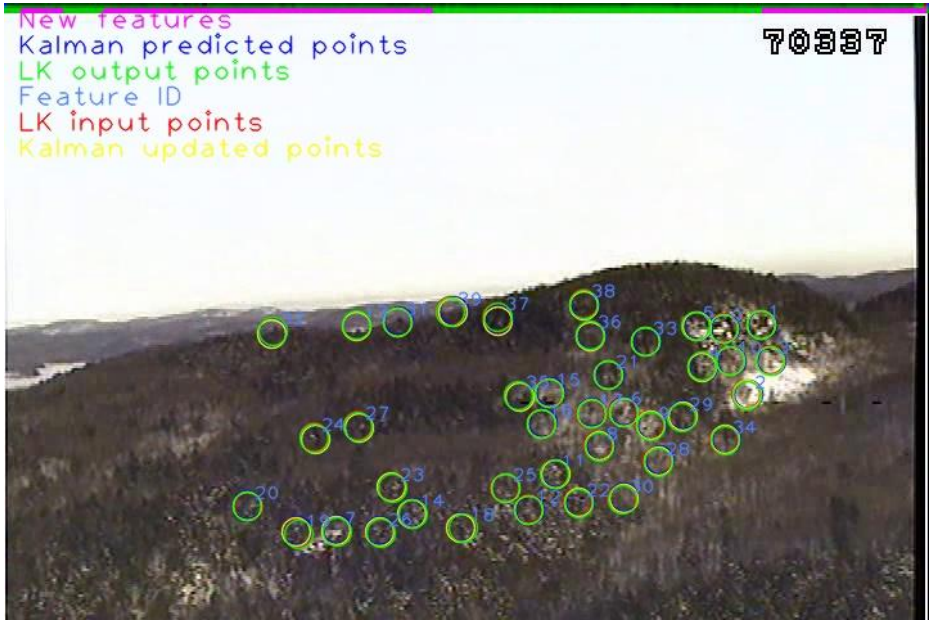
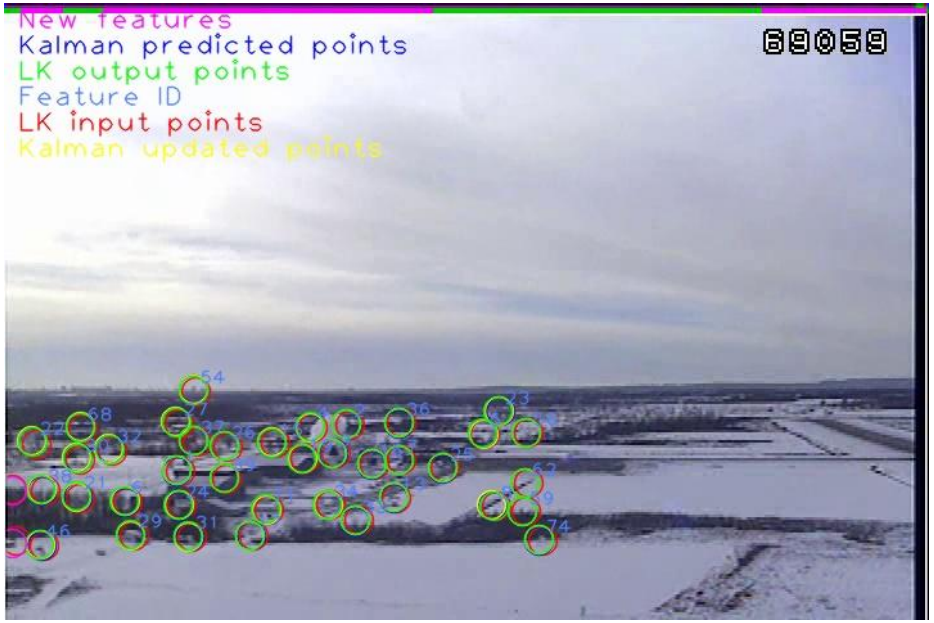
Contribution 3: Aerial Data Processed by CC-EKF-SLAM

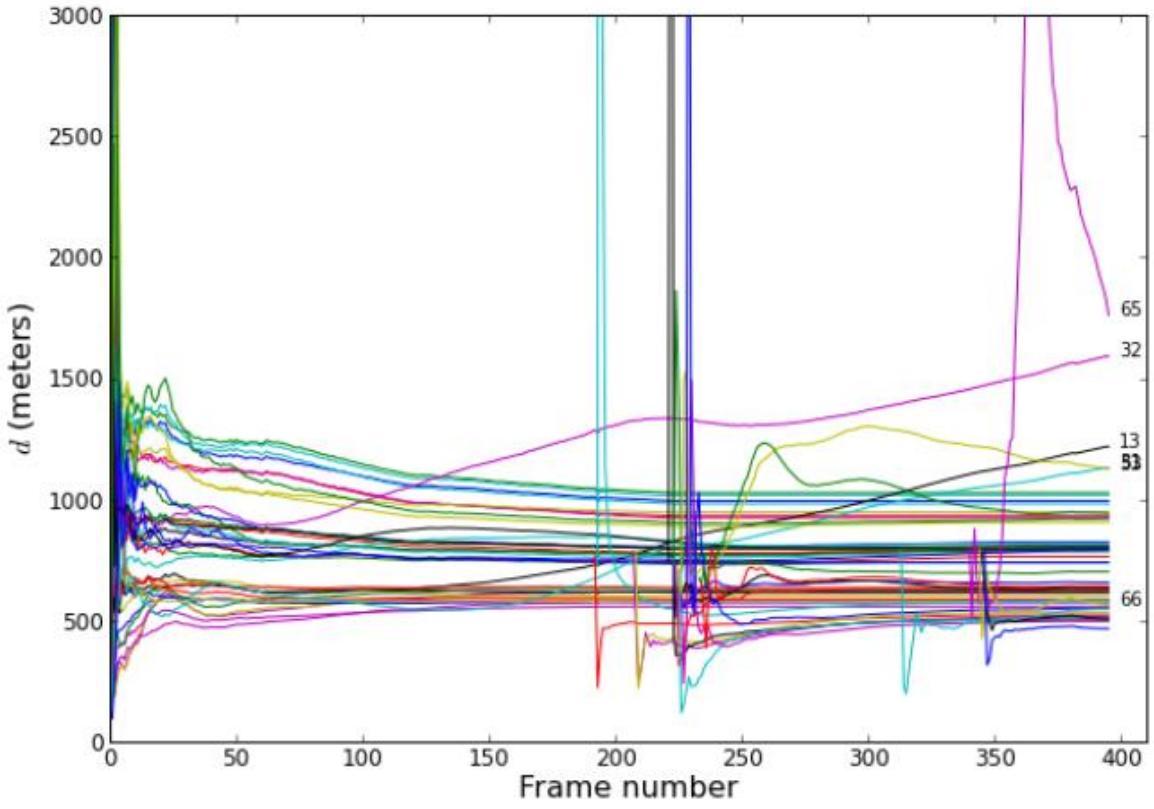
Natural Scene



Airport Landing Scene



Contribution 3: Flight Result
Convergence Analysis



Landmark 13 at various frames

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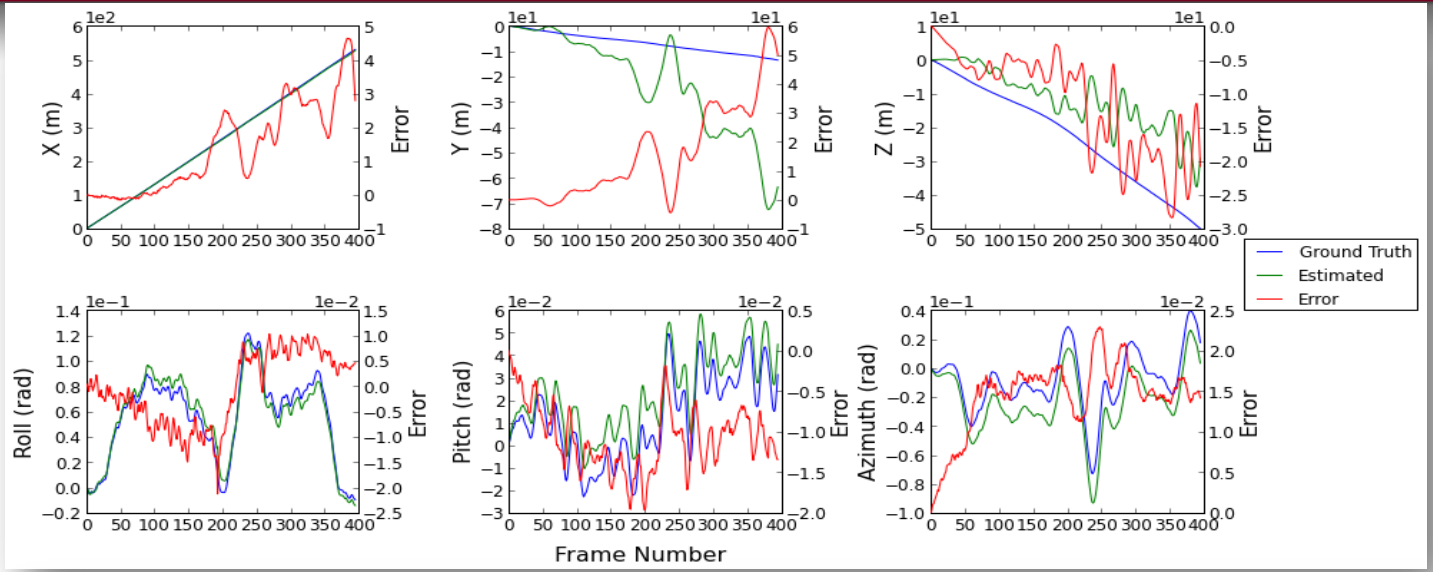
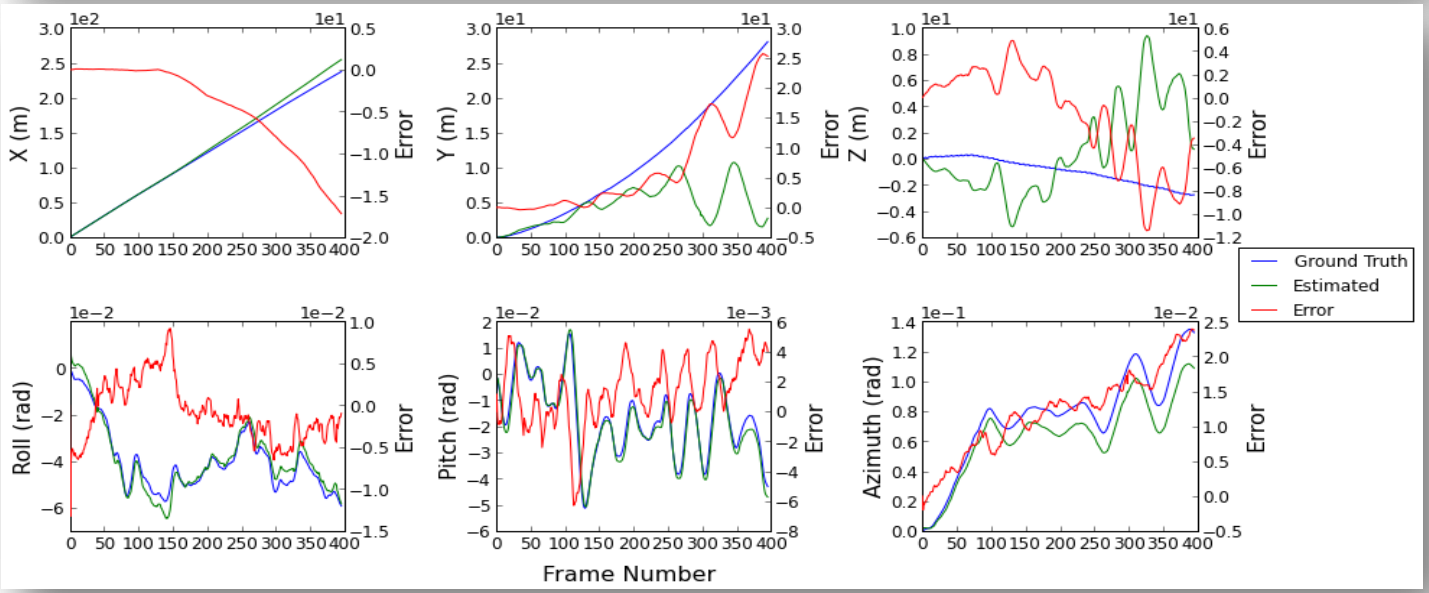
Contribution 3: Flight Result
SUAS Localization

Natural Scene



Airport Landing Scene



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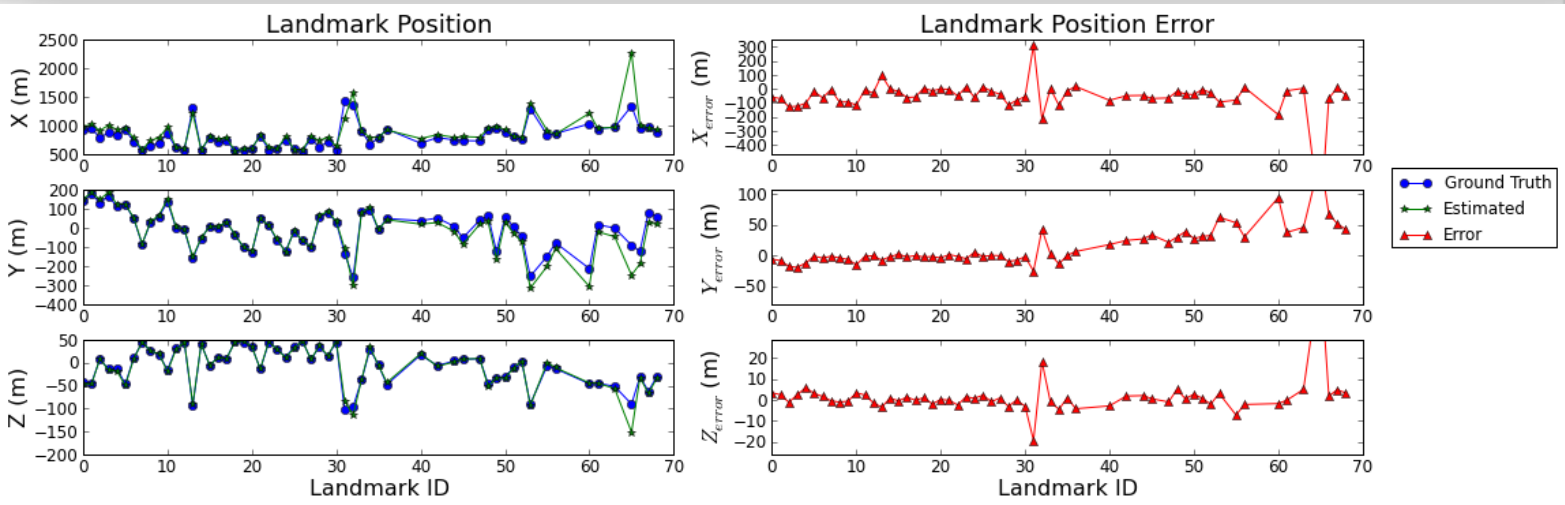
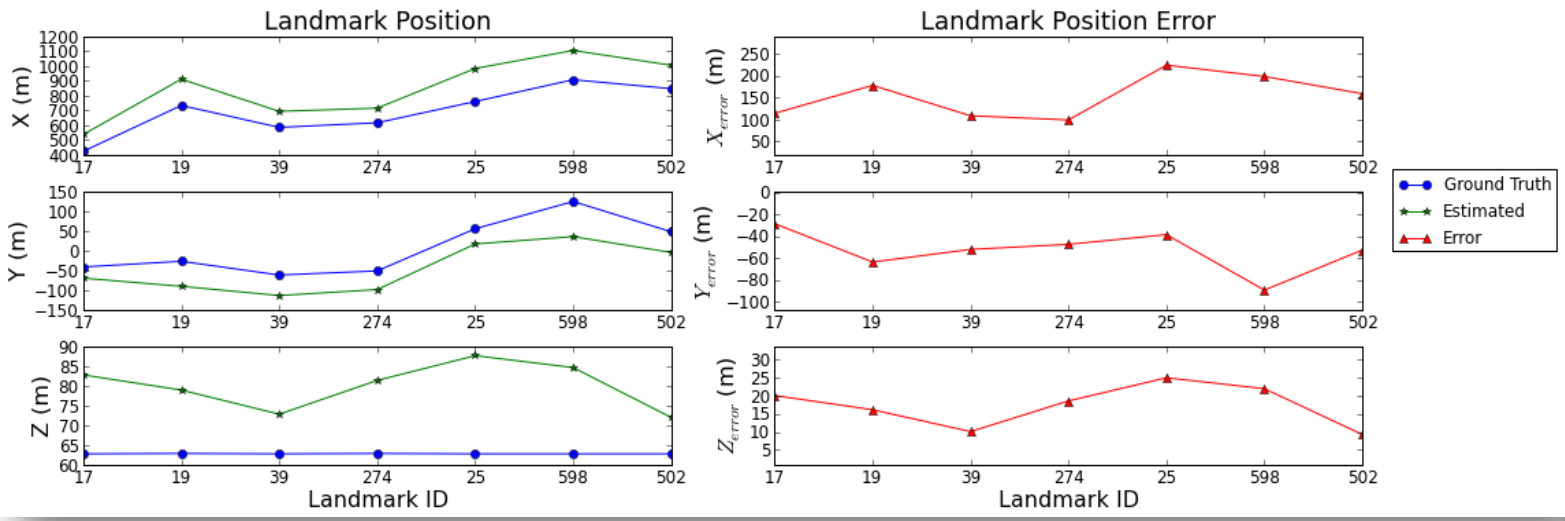
Contribution 3: Flight Result
Landmark Mapping

Natural Scene



Airport Landing Scene



Contribution 3: Flight Result

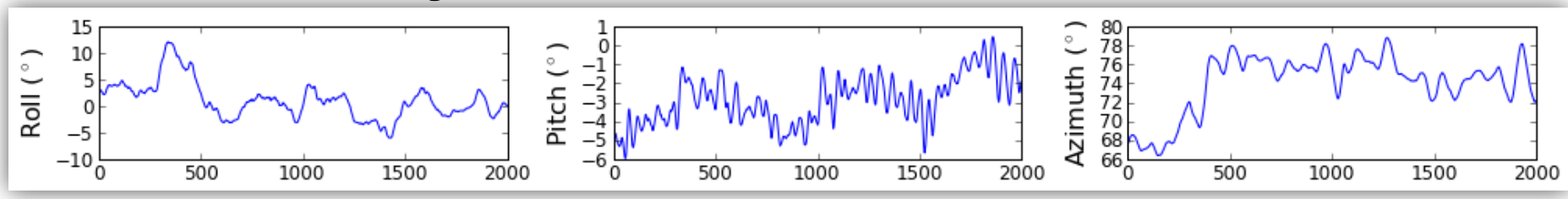
- **This contribution is published in**

The 2012 IEEE International Instrumentation and Measurement Technology Conference

[7] F. Zhang, R. Goubran, and P. Straznicky, "Obstacle detection for low flying UAS using monocular camera," in *Proceedings of the IEEE International Instrumentation and Measurement Technology Conference*, 2012, pp. 2133-2137.

Contribution 4: Error Analysis

- **Oscillatory Motion of the UAV**

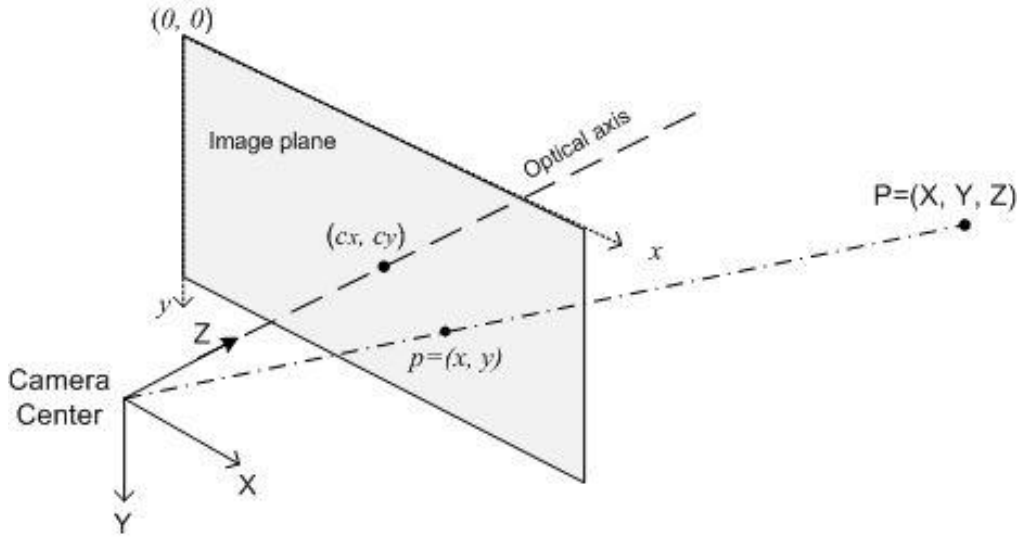


- **Error from Camera Calibration**

$$x = f_x \left(\frac{X}{Z}\right) + c_x$$

$$y = f_y \left(\frac{Y}{Z}\right) + c_y$$

- **Image Resolution**



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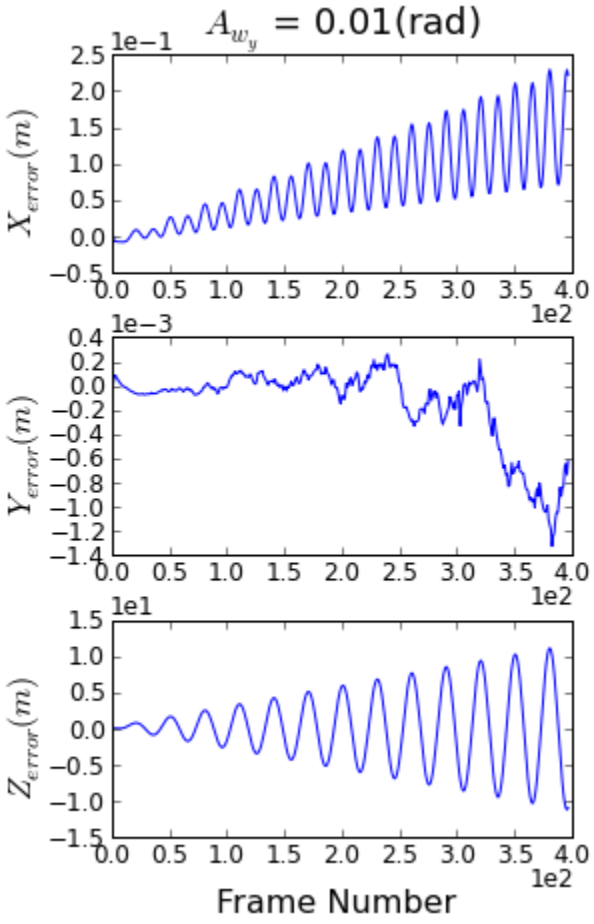
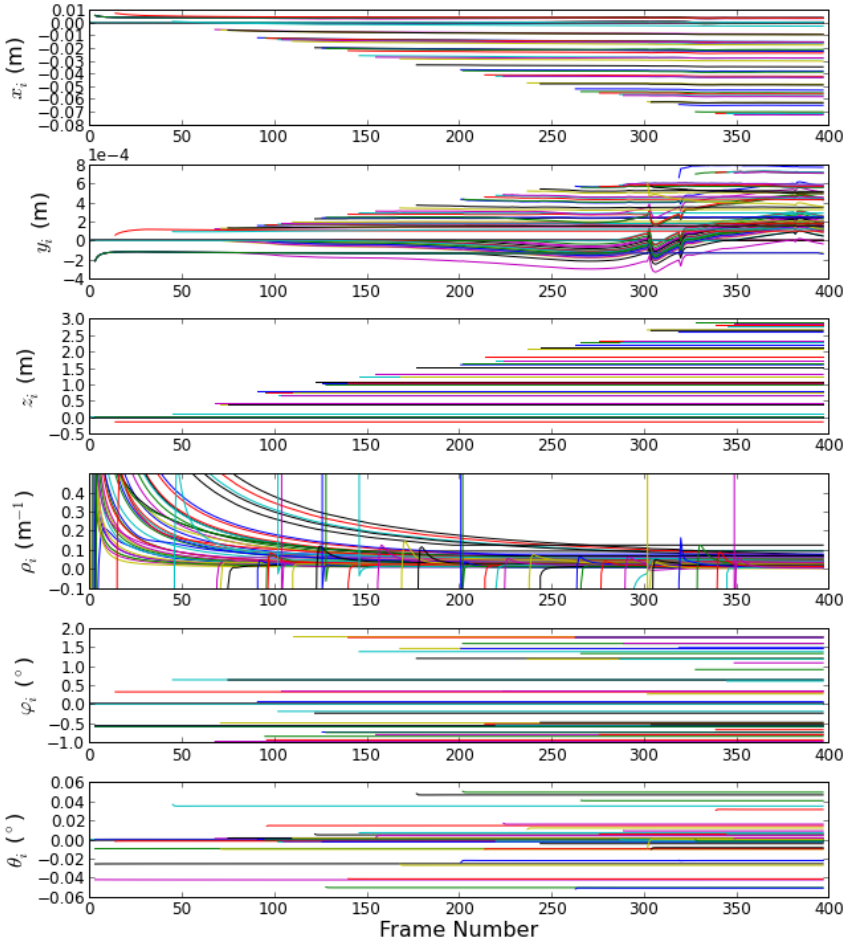
Contribution 4: Error Analysis
Effect of Oscillatory Rotation





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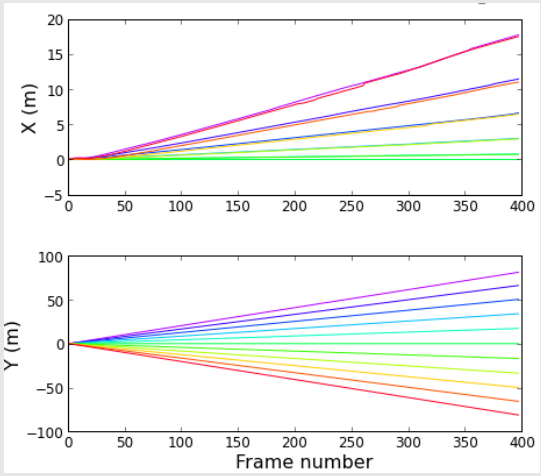
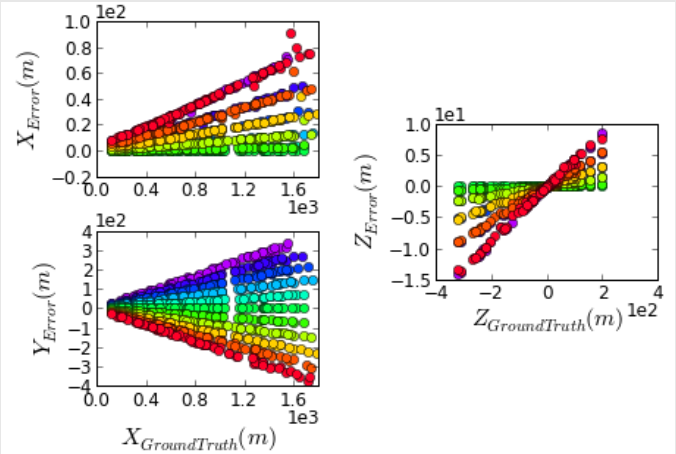
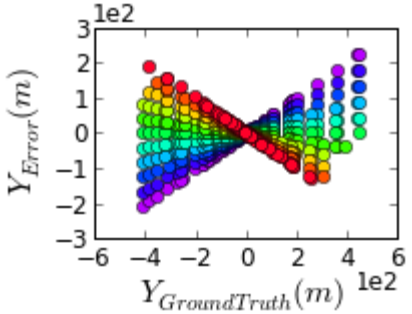
Contribution 4: Error Analysis
Effect of Camera Calibration Error and Image Resolution

	UAV Localization	Landmark Mapping
c_x (c_y affects different axes)		
f_x (f_y affects different axes)	No Effect	

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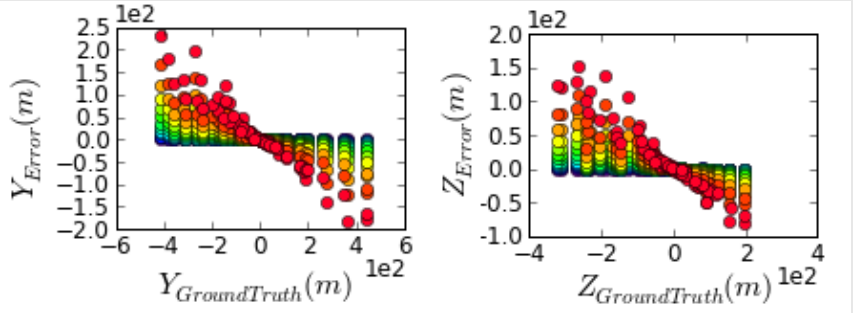
Contribution 4: Error Analysis

Effect of Camera Calibration Error and Image Resolution

	UAV Localization	Landmarks Mapping
Lens Distortion	Diverging Error	
Image Resolution	1080 x 1440 or higher	1080 x 1440 or higher

Conclusion

- Contribution 1:

  Aerial Video and Data Collected through Test Flight

- Contribution 2:

  CC-EKF-SLAM Implemented

- Contribution 3:

  Aerial Data Processed by CC-EKF-SLAM

- Contribution 4:

  Error Analysis

Recommendations for Future Work

- Add lens distortion model
- Increase sensor resolution
- Add landmark quality checking and filtering function
- Research on map joining algorithm
- Increase accuracy by syncing to GPS
- Investigate on the sensitivity problem to oscillatory rotation

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Acknowledgement

- Rafik Goubran, Paul Straznicky
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