- Good morning examiners and audiances
- My name is
- My thesis topic is

Introduction

- Know distance and direction of the obstacle
- Sensors
  - Lidar etc requires 2D scanning
  - 3D flash lidar: expensive
  - Imaging Sensor: inexpensive, small, many options
- Configuration: bearing only, requires >2 frames
  - Binocular: stereoscopic, like human eye
  - Monocular: optical flow
- Computer Algorithm
  - Machine vision: process images
  - SLAM:

    *Data fusion *estimate UAV trajectory * landmark position

Problem Statement

- Targetted Application
  - Small – Mid size UAV,
  - Low Altitude, Terrain Following
  - High resolution geological survey
- Scenario
  - Digital Elevation Map → Flight Path Planning
  - Low resolution
  - UAV detect discrete threat and fly around

Problem Statement

- How far away ?
- Based on GeoSurvII specs
- tree height 20 meter
- flying at minimum altitude
- Obstacle clearance 10 meters
  - 300 meters at 60 knots
  - 500 meters at 100 knots

Problem Statement

- Solution:

1. Capture image sequence of natural scene
2. Extract visual feature from image, assocated physical point is Landmark
3. Combine feature tracking and UAV motion
4. Get UAV trajectory and sparse terrain map

Contribution 1

- Real Aerial Video and Navigation Data
- Test flight conducted by SGL
- SUAS carried sensors, towed by helicopter
- Helicopter at 100m above ground, SUAS at 60-70 above ground
- Test Site, mountain north of Gatineau

Contribution 1 – Sensors and equipment

- Sensors on SUAS
  - Wide angle 6mm monocular camera 30fps
  - Narrow angle binocular cameras
  - GPS antenna
  - GS-111M INS/GPS navigation unit, with external fluxgate
  - Data sent through BNC and RS485
- Helicopter
  - CDAC
  - Monitors for operator

Contribution 1 – flight video

- CCD camera has 480x720 resolution, digitized to 480x720 pixels
- GPS second timestamped

Contribution 1- camera calibration

- Calibration target – checkerboard
- 20 views are fed to calibration algorithm
- Results

Contribution 2 – CC-EKF-SLAM

- Input:
  - Monocular image sequence
  - Velocity, acceleration, SUAS orientation
- Algorithm:
  - EKF based
  - SLAM
- Output:
  - UAV Trajectory
  - Landmark locations

Contribution 2 – CC-EKF-SLAM

- Algorithm features:
  - Inverse depth parameterization
  - All parameters referenced to camera frame
  - Deletion and addition of landmark for continuous operation

Contribution 3 – Test flight result

- Two pieces of video were processed by CC-EKF-SLAM
  - Natural Scene
  - Airport Landing Scene
    - For manual correspondence of estimated landmark and ground truth

Contribution 3 - Convergence

- Most Landmark converged in 20-30 frames
- Some drift away
  - Landmark located on hill top
  - Visual tracking algo allows for small error to accommodate camera view change and noise
- Landmark 13
  - Original feature at hill top
  - End feature at mountain behind lake

Contribution 3 – SUAS localization

- Estimated result in general agree with ground truth
- X axis position has good accuracy
- Y and Z axis has more noise
- Orientation estimates has some offset error
- Y and Z position error correlated with orientation

Contribution 3 – Landmark mapping

- Average landmark distance ~ 1000m
  - CC-EKF-SLAM able to map object at 1000m
- Landmark with ID > 40 has offset error
  - They are not initialized at 1st frame
  - Error analysis shows the source of these error
- Airport landing scene,
  - Offset on all axis
  - Landmark located on corner of image
  - Lens distortion

Contribution 3 – Publication

- Result of test flight were published in 2012 IEEE I2MTC

Contribution 4 – Error Analysis

- Analyze algorithm performance under several scenario
- Oscillatory motion of UAV
  - Flight data show oscillatory rotation on pitch and heading
- Error in camera calibration
  - Camera calibration result is different with change in input images
  - Estimate has error, and what’s the impact?
- Sensor resolution
  - For future sensor selection

Contribution 4 – Oscillatory rotation

- CC-EKF-SLAM sensitive to oscillatory rotation
- Example: Oscillatory rotation around Y
  - Localization: Oscillating and diverging error on X and Z
  - Mapping:
    - Result of localization error
    - Offset error for landmark added after 1st frame
    - Error caused by coordinates transformation from camera frame to world frame

Contribution 4 – Calibration error and sensor resolution

- Error in Cx, Cy, (coordinate of optical axis on image)
  - Impact both localization and mapping
  - Error model by 1st order polynomial
- Error in fx, fy, (scaling factor from world to image)
  - No impact on localization,
  - Mapping error model by 1st order polynomial

Contribution 4 – Calibration error and sensor resolution

- Lens Distortion
  - Diverging error in localization
  - Mapping error proportional to landmark distance to optical axis on image
- Sensor resolution
  - > 1080x1440 for targeted distance

Conclusion

Recommendation for future work

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- Family
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