Fusion of Monocular Visual-Inertial Measurements for Three Dimensional Pose estimation

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Outline

Introduction and Objectives

Flying robots

Fixed-wing airplanes

Helicopters

Quadrotors

Quadrotors are in the focus of interest because ...

- are inexpensive
- are easy to build and to maintain
- are easy to control
- can keep position
- are appropriate for autonomous flight

Introduction and Objectives

Autonomous flight

Low level control

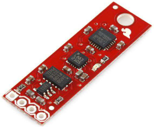
- maintain attitude, stabilize
- disturbance compensation

High level control

- drift compensation
- obstacle avoidance
- localization and mapping
- navigation to a point
- ...

Introduction and Objectives

Common sensors



Inertial sensors

Camera

Sonar

Magnetic compass

GPS

Problems

- sensors are noisy
- measurements can be partial
- potentially missing

Introduction and Objectives

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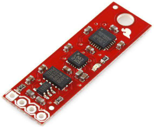

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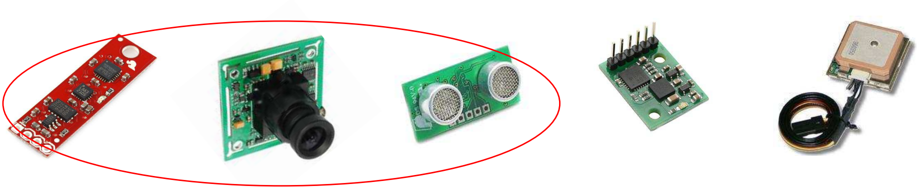

Inertial sensors | Camera | Sonar | Magnetic compass | GPS

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Challenge

Improve the pose estimation for indoor and outdoor environments

System Overview

- Estimation of the position and orientation of a UAV using inertial sensors, a monocular camera, and an altimeter.
- The visual algorithm uses the so called spectral features, and is based on the plane-induced homography when observing a flat floor.

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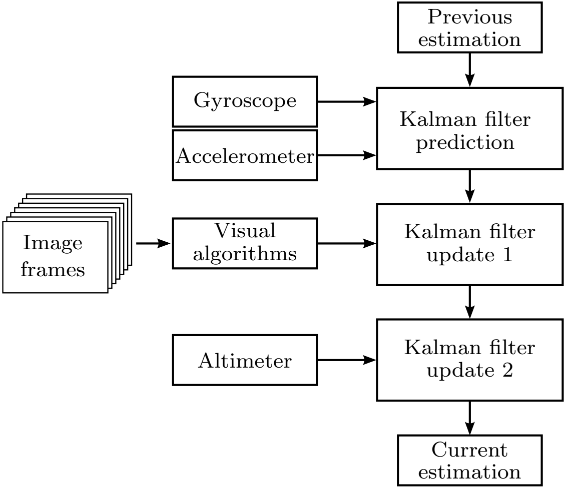


Sensor Fusion

State vector and inertial models

- State vector and error

$$\mathbf{x} = \begin{bmatrix} \mathbf{p} \\ \mathbf{v} \\ \mathbf{q} \end{bmatrix}, \quad \delta\mathbf{x} = \begin{bmatrix} \delta\mathbf{p} \\ \delta\mathbf{v} \\ \delta\boldsymbol{\theta} \end{bmatrix}$$

- Inertial sensors (input signal)

$$\mathbf{u} = \begin{bmatrix} \mathbf{a}_m \\ \boldsymbol{\omega}_m \end{bmatrix}, \quad \begin{cases} \mathbf{a}_m = \mathbf{a} + \mathbf{w}_a \\ \boldsymbol{\omega}_m = \boldsymbol{\omega} + \mathbf{w}_\omega \end{cases}$$

- Process model, $\dot{\mathbf{x}} = f(\mathbf{x}, \mathbf{u})$

$$\begin{aligned} \dot{\mathbf{p}} &= \mathbf{v} \\ \dot{\mathbf{v}} &= \mathbf{R}(\mathbf{q})\mathbf{a} + \mathbf{g}^n \\ \dot{\mathbf{q}} &= \frac{1}{2}\mathbf{q} \otimes \begin{bmatrix} 0 \\ \boldsymbol{\omega} \end{bmatrix} \end{aligned}$$

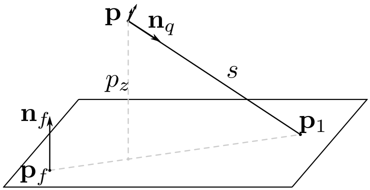
Sensor Fusion
Measurement models

- Camera measurement model, ${}^{c}\mathbf{z} = h_c(\mathbf{x})$

$$ {}^{c}\hat{\mathbf{z}}_k^- = \begin{bmatrix} {}^{c}\hat{\mathbf{p}}_k^- \\ {}^{c}\hat{\mathbf{q}}_k^- \end{bmatrix} $$

(relative position and orientation between consecutive frames)

- Altimeter measurement model, ${}^{a}z = h_a(\mathbf{x}) = p_z$



Visual Algorithm

Homography-based pose estimation

Considerations

- two images of a planar scene are related by a homography
- a downward-looking camera observes the floor (assumed flat)
- the homography encodes the spatial transformation of the camera

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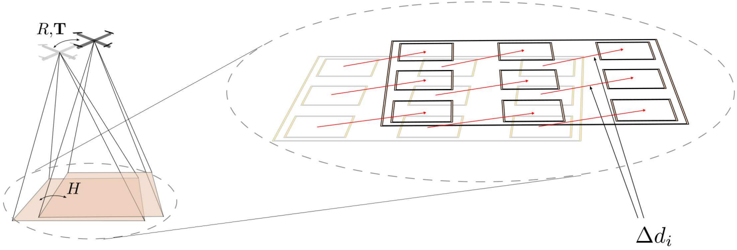
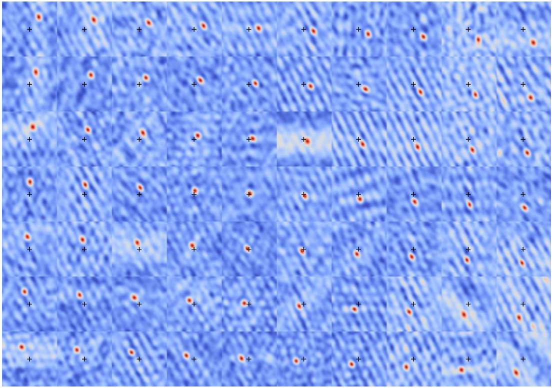
Corresponding points



$$\{\mathbf{x}_{A_i} \leftrightarrow \mathbf{x}_{A_i} + \Delta\mathbf{d}_i = \mathbf{x}_{B_i}\}$$

Visual Algorithm

Spectral Features

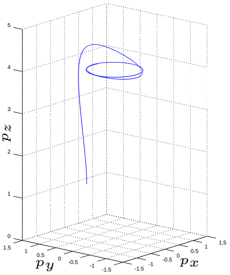


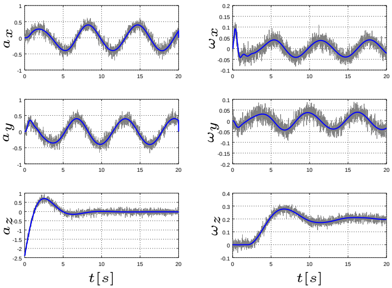
$$\{\mathbf{x}_{A_i} \leftrightarrow \mathbf{x}_{A_i} + \Delta\mathbf{d}_i = \mathbf{x}_{B_i}\} \quad (1)$$

Results

Synthetic Dataset

Based on a dynamic simulation of a quadcopter, which allows to obtain the ground truth position and orientation, together with the ideal inertial sensor measurements.





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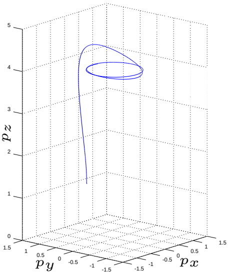
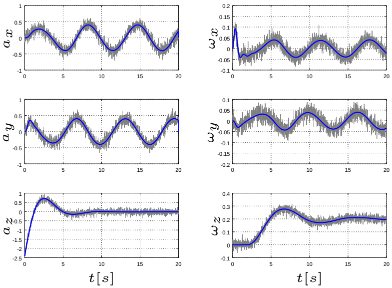
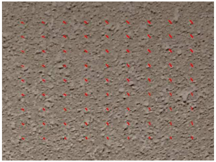
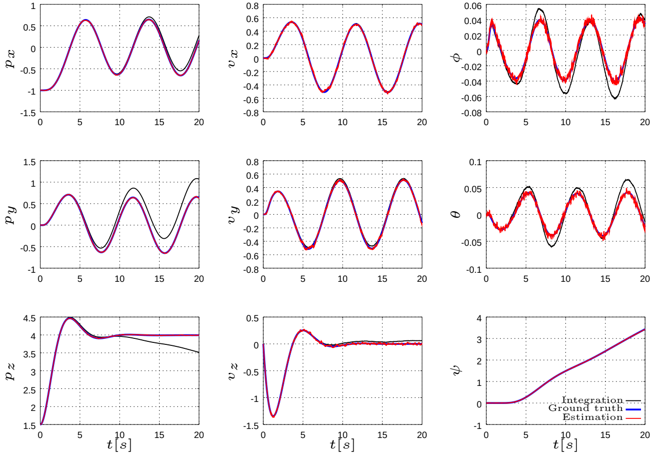






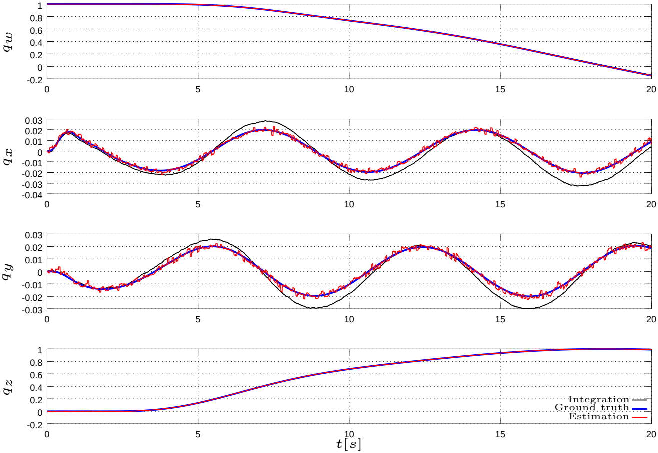
Results

Estimated position, velocity and orientation



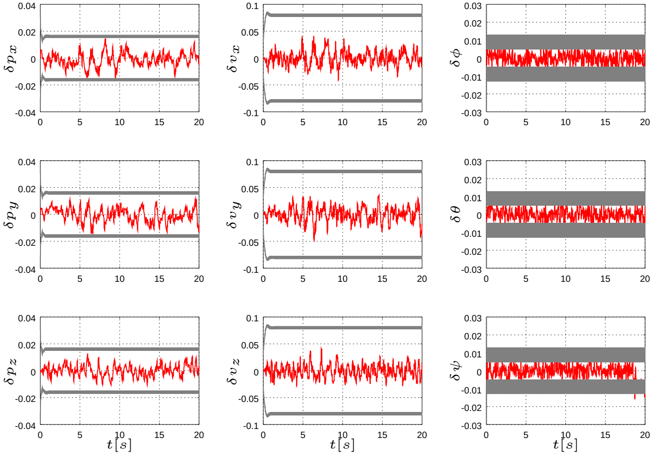
Results

Estimated orientation (unit quaternion)



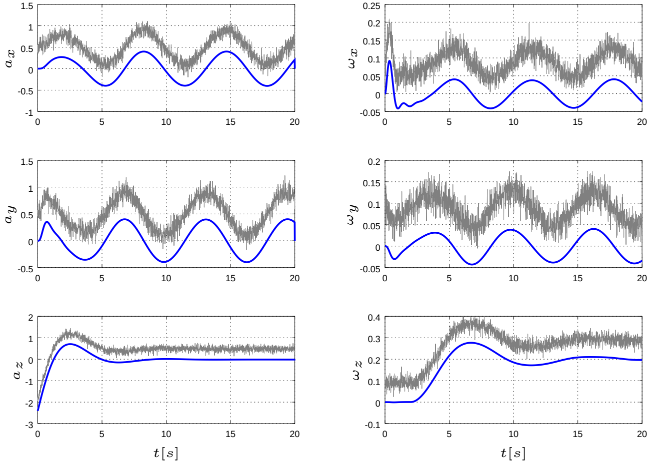
Results

Estimation error



Results

IMU measurements with constant bias



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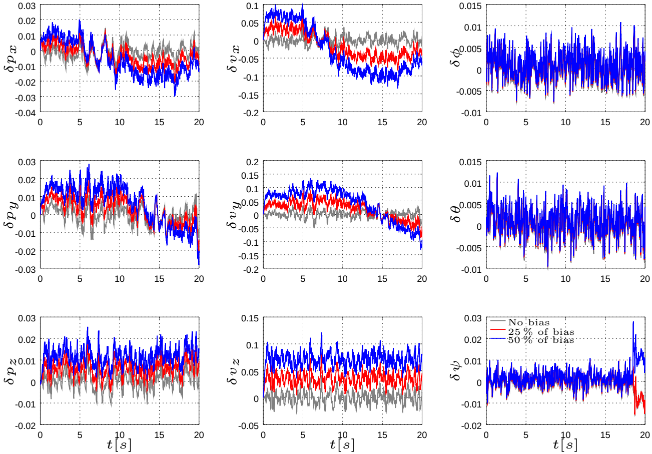

Conclusion and Future Work

- The three dimensional pose estimation has a precision that seems promising to be applied in UAV on-board algorithms for control purposes.
- A not precise bias correction, as high as 50 % of the real bias, does not affect pose estimation considerably, specially for short time flights.
- Test the proposed fusion schema with a real UAV, in order to evaluate how the estimation is affected by real sensor noise and unmodeled sensor bias.
- Formulate a new filter model incorporating the sensor biases in the state vector in order to be estimated.
- Compare the proposed visual algorithm with other similar approaches, particularly those that does not use corner-like features.

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Thanks for your attention.