Visual homography-based pose estimation of a quadrotor using spectral features

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Outline

Flying robots

Fixed-wing airplanes

Helicopters

Quadrotors

Quadrotors are in the focus of interest because ...

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

Autonomous flight

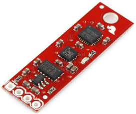
Low level control

- maintain attitude, stabilize
- disturbance compesation

High level control

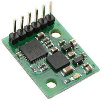
- drift compesation
- obstacle avoidance
- localization and mapping
- navigation to a point
- . . .

Common sensors


Inertial sensors


Camera


Sonar

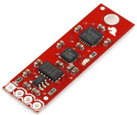

Magnetic compass


GPS

Problems

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

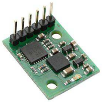
Common sensors



Inertial sensors

Camera

Sonar



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GPS

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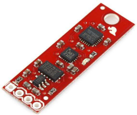
- sensor fusion is required

Common sensors

				
Inertial sensors	Camera	Sonar	Magnetic compass	GPS

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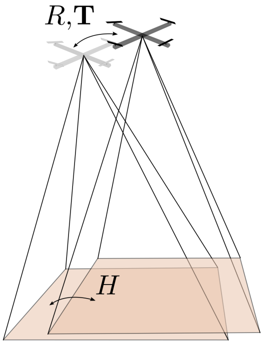
Challenge

Improve the visual pose estimation 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



$$\boldsymbol{H} \rightarrow \{\boldsymbol{R}, \boldsymbol{T}\}$$

Plane-induced homography

Relation in 3D coordinates

Given a 3D scene point $\boldsymbol{P}$ and two coord. systems CS_A and CS_B

$$\boldsymbol{X}_B = \boldsymbol{R}_A^B \boldsymbol{X}_A + \boldsymbol{T}_B. \quad (1)$$

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If $\boldsymbol{P}$ belongs to a plane π

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then

$$\boldsymbol{X}_B = \left(\boldsymbol{R}_A^B + \frac{\boldsymbol{T}_B}{d_A} (\boldsymbol{n}_A)^T \right) \boldsymbol{X}_A = \boldsymbol{H}_A^B \boldsymbol{X}_A, \tag{3}$$

with

$$\boldsymbol{H}_A^B \doteq \left(\boldsymbol{R}_A^B + \frac{\boldsymbol{T}_B}{d_A} (\boldsymbol{n}_A)^T \right). \tag{4}$$

Plane-induced homography

Camera projection

Considering a moving camera, the coordinate system at time t_A can be represented by the CS_A, and at time t_B by the CS_B.
That is

$$\lambda_A \boldsymbol{x}_A = \boldsymbol{X}_A; \quad \lambda_B \boldsymbol{x}_B = \boldsymbol{X}_B \tag{5}$$

with $\boldsymbol{x}_A, \boldsymbol{x}_B \in \mathbb{P}^2$ (homogeneous coordinates).

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Given that $\boldsymbol{X}_B = \boldsymbol{H}_A^B \boldsymbol{X}_A$

$$\boldsymbol{x}_B = \lambda \boldsymbol{H}_A^B \boldsymbol{x}_A \tag{6}$$

with $\lambda = \frac{\lambda_A}{\lambda_B}$.

Plane-induced homography

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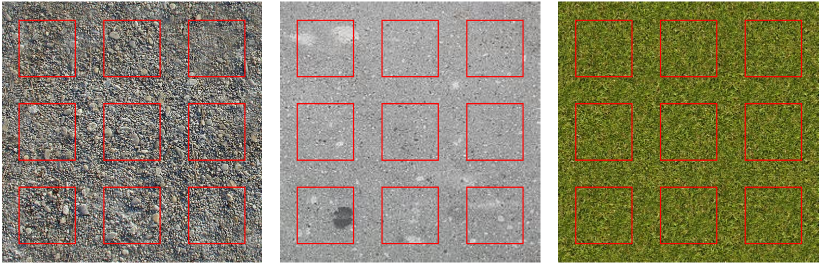
with $\lambda = \frac{\lambda_A}{\lambda_B}$.
Then, from a set of corresponding points $\{\boldsymbol{x}_A^i \leftrightarrow \boldsymbol{x}_B^i\}$ (with $i > 4$), the homography can be estimated.

Spectral features

Spectral features



Phase Correlation Method

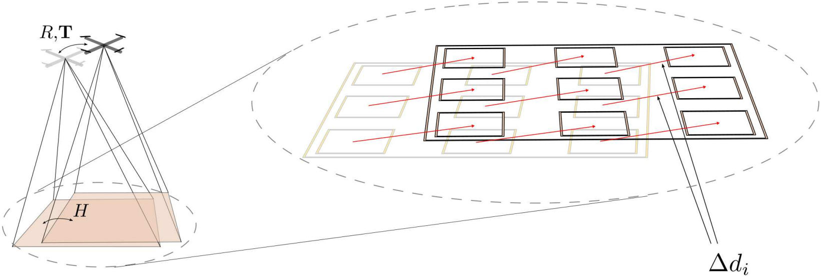
Given two displaced images $i_A(x,y) = i_B(x-u, y-v)$, their Fourier transforms are related by

$$I_A(\omega_x, \omega_y) = e^{-j(u\omega_x + v\omega_y)} I_B(\omega_x, \omega_y), \tag{7}$$

$$\frac{I_A I_B^*}{|I_A||I_B^*|} = e^{-j(u\omega_x + v\omega_y)}. \tag{8}$$

Spectral features

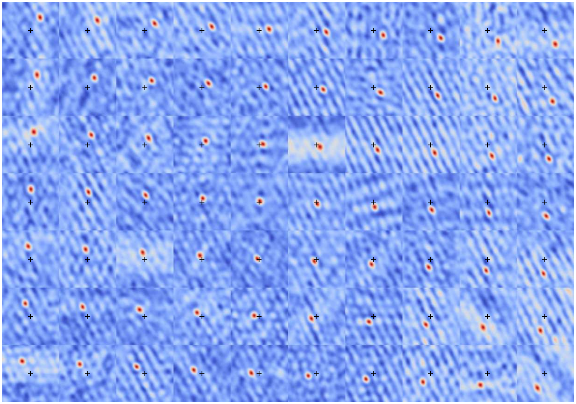
Corresponding points



$$\{\boldsymbol{x}_{A_i} \leftrightarrow \boldsymbol{x}_{A_i} + \Delta \boldsymbol{d}_i = \boldsymbol{x}_{B_i}\} \quad (9)$$

Spectral features

Real set of spectral features displacement estimation



$$\{\boldsymbol{x}_{A_i} \leftrightarrow \boldsymbol{x}_{A_i} + \Delta \boldsymbol{d}_i = \boldsymbol{x}_{B_i}\} \tag{10}$$

Homography decomposition

From $\{\boldsymbol{x}_A^i \leftrightarrow \boldsymbol{x}_B^i\}$ we have

$$\boldsymbol{H}_\lambda = \lambda \left(\boldsymbol{R} + \frac{\boldsymbol{T}}{d} \boldsymbol{n}^T \right) \tag{11}$$

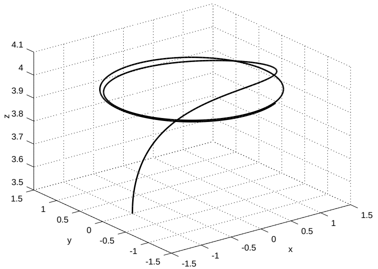
The estimation of λ, $\boldsymbol{n}$, $\frac{\boldsymbol{T}}{d}$ and $\boldsymbol{R}$ results in:

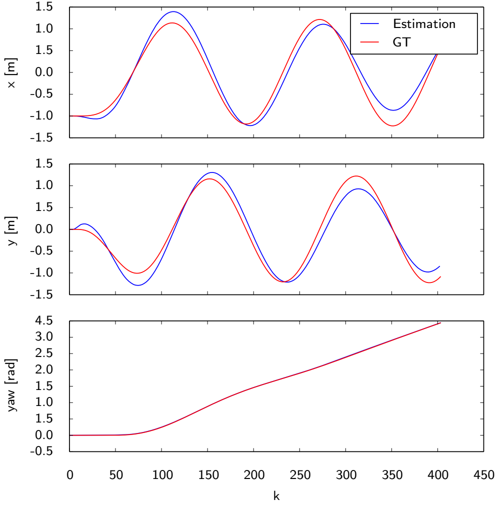
$$\begin{aligned} &\left\{ \boldsymbol{R}_1, \boldsymbol{n}_1, \tfrac{\boldsymbol{T}_1}{d_1} \right\}, \quad \left\{ \boldsymbol{R}_1, -\boldsymbol{n}_1, \tfrac{-\boldsymbol{T}_1}{d_1} \right\}, \\ &\left\{ \boldsymbol{R}_2, \boldsymbol{n}_2, \tfrac{\boldsymbol{T}_2}{d_2} \right\}, \quad \left\{ \boldsymbol{R}_2, -\boldsymbol{n}_2, \tfrac{-\boldsymbol{T}_2}{d_2} \right\} \end{aligned} \tag{12}$$

- Only two are fisically possible (points in front of the camera).
- The correct transformation is chosen by applying a motion restriction.

Implementation and simulation results

- OpenCV library for image processing and computer vision algorithm.





Conclusion and future work

- Appropriated for a sensor fusion schema (x, y and ψ)
- Decomposition does not require high computational cost
- The use of Spectral features present some benefits (easy to initialize, no need to search, balanced distribution)
- They can be used together with the classical intensity features
- The z coordinates is obtained from another sensor (barometer, sonar)
- Testing in real quadrotors, fusion with IMU and another sensors, add z to the state vector

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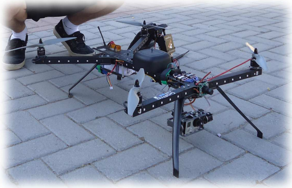

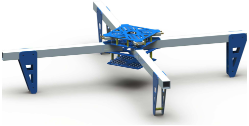

Thanks for your attention.