Trajectory Recovery and 3D Mapping from Rotation-Compensated Imagery for an Airship.

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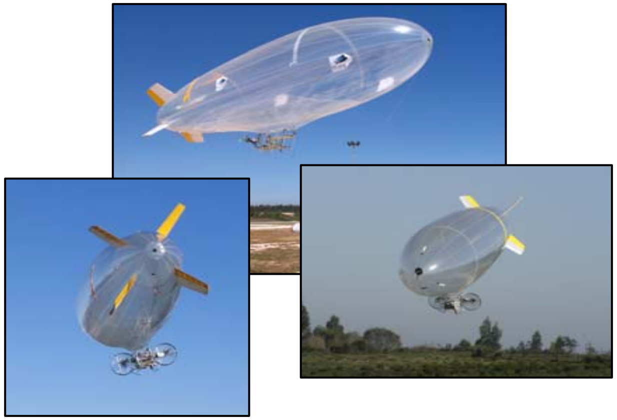

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Outline

- **Review**
  - Camera Inertial Calibration
  - Projecting images on a virtual stabilized plane.
  - Relative Pose from two images of a planar patch (homography)

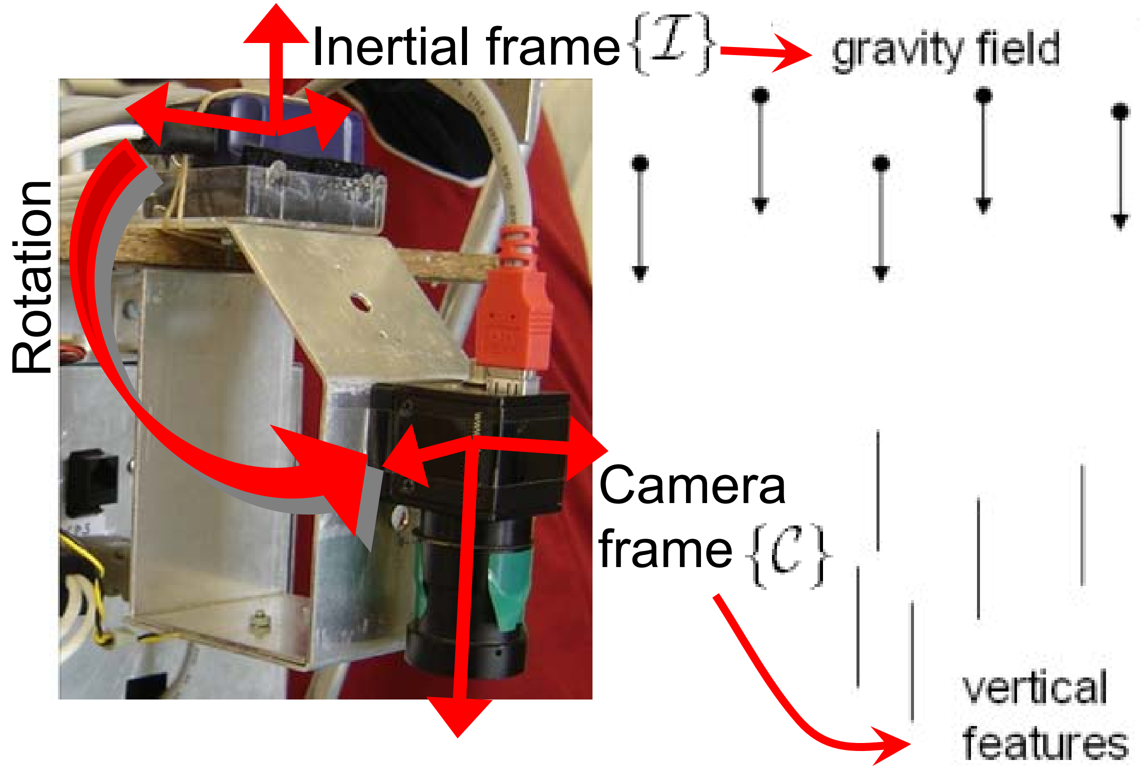
- Visual Navigation
  - Relative Pose with rotation compensated
  - Height estimation for airship UAV
  - Trajectory estimation for airship UAV
  - Evaluating the recovered height using the homography

- 3D Mapping from image ratios

- Conclusions

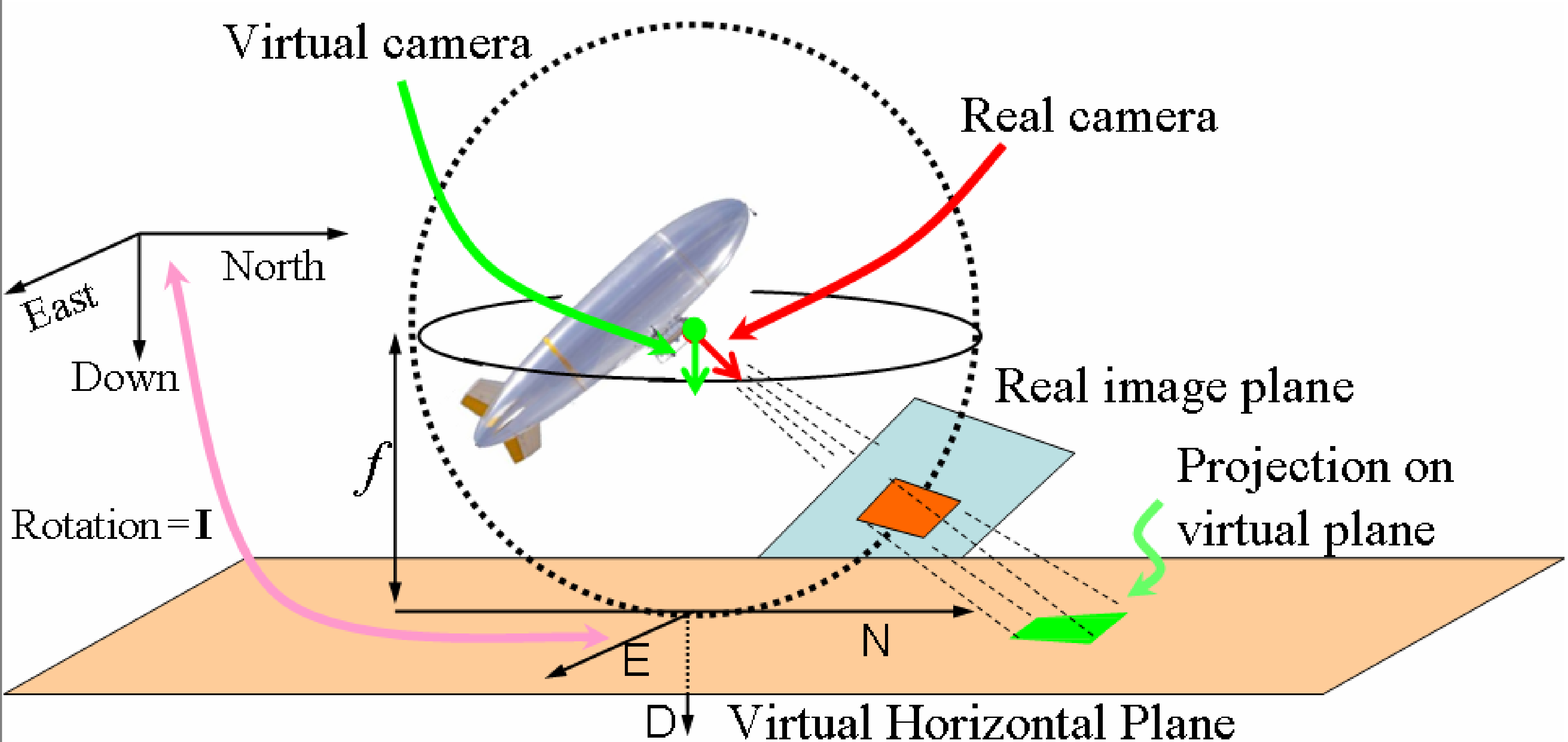
Camera-Inertial calibration

- Camera-Inertial Calibration
  - Rigid mounting
  - IMU: gravity vector
  - CAM: vertical lines
  - Recover rotation between $\{\mathcal{I}\}$ and $\{\mathcal{C}\}$
  - MATLAB Toolkit
- Conclusion:
  - Inertial system measures camera orientation



[LD05] Jorge Lobo and Jorge Dias. Relative pose calibration between visual and inertial sensors. In *ICRA 2005 Workshop on Integration of Vision and Inertial Sensors - 2nd InerVis*, Barcelona, Spain, April 18 2005.

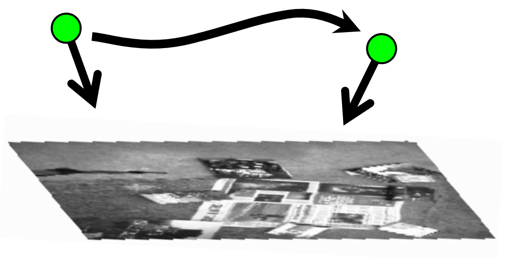
Projecting images on a virtual stabilized plane



- The projection is done by the infinite homography [Hartley & Zisserman, 2000]

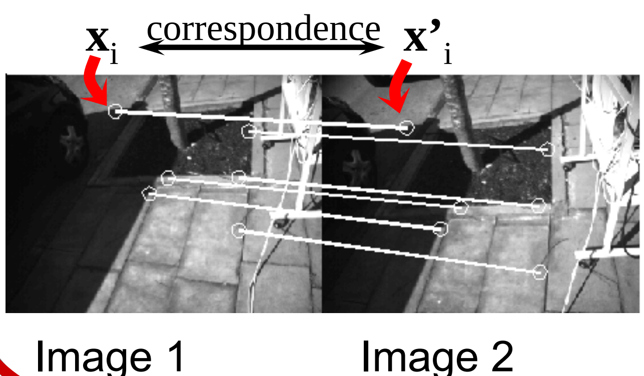
Relative Pose from two images of a planar patch

- moving Camera images planar surface



- establish pixel correspondences

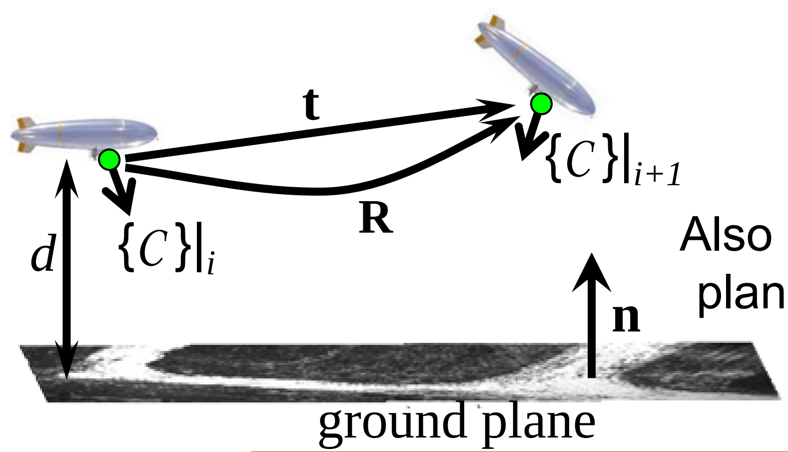
SURF [Bay et al, 2006]



- Recover homography matrix [Hartley and Zisserman, 2000]
  - RANSAC
  - homography transformation:

$$\mathbf{x}'_i = H\,\mathbf{x}_i$$

- Decompose 3x3 matrix H, to obtain:
  - rotation R, plane normal **n,** translation **t/d**
  - only **t/d,** not magnitude
  - inherent scale ambiguity



Also recovers plane normal **n**

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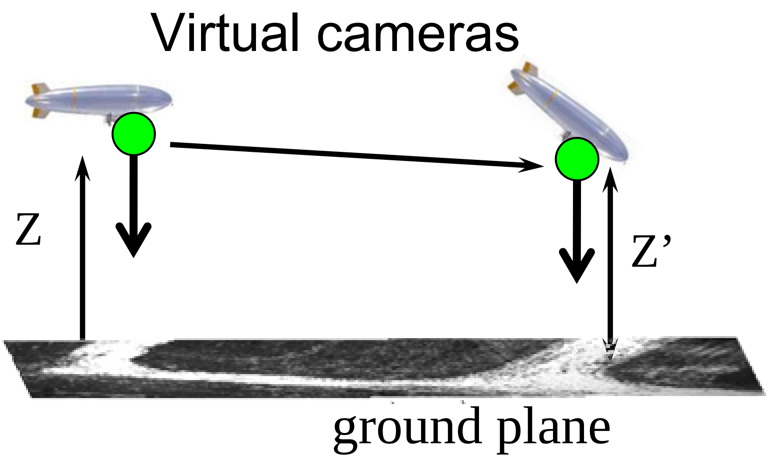
Relative Pose with rotation compensated

- Images are projected on the horizontal ground plane
  - Plane normal is known
- No rotation (R = I)
- homography → planar homology.
- Planar homology reduced to:

$$G = \begin{bmatrix} 1 & 0 & (\mu - 1) \cdot v_x \\ 0 & 1 & (\mu - 1) \cdot v_y \\ 0 & 0 & \mu \end{bmatrix}$$

- where $\mathbf{v} = (v_x, v_y, 1)$ is the FOE (focus of expansion), *i.e.*, the epipole,

Estimated from pixel correspondences [Chen et al., 2003]



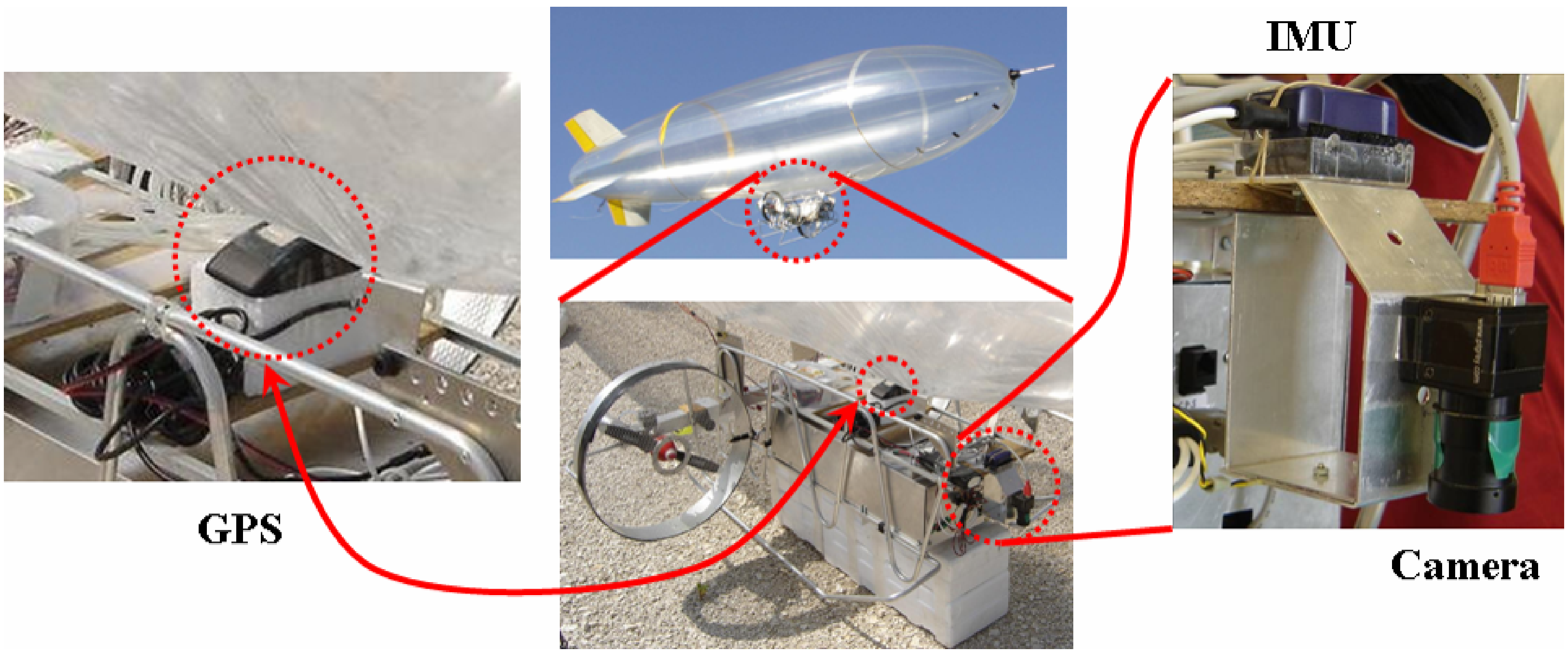
- and μ is the relative depth of the plane
- scale ambiguity: just <u>relative</u> depth!

$$\frac{Z'}{Z} = \frac{dist(\mathbf{x}, \mathbf{v})}{dist(\mathbf{x}', \mathbf{v})} = \mu$$

- Small scale experiment w/ ground truth demostrate better accuracy on μ [Mirisola and Dias, 2007]

Height estimation for airship UAV

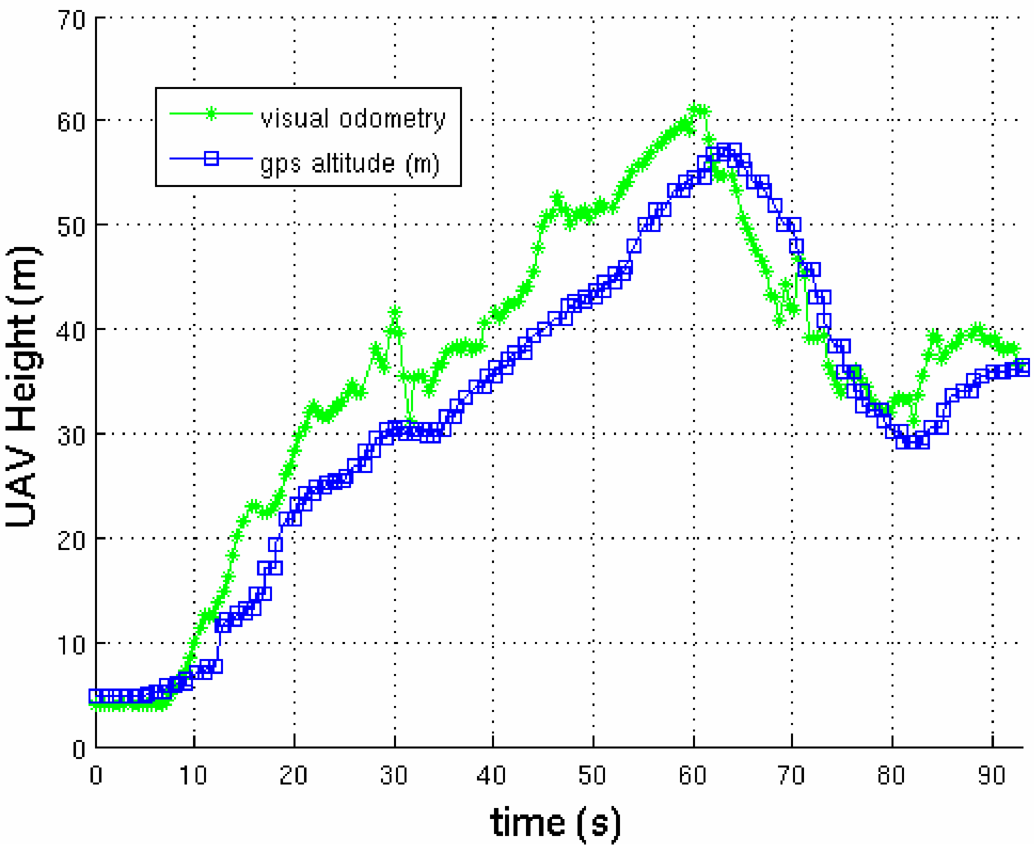
- IMU – CAM mounted on remotely controlled airship, with GPS



Height estimation for airship UAV

- Airship flight, remotelly piloted

Height estimation for airship UAV



- Airship flies over planar airport.
- Height of 1st image = 4m
  - solves scale ambiguity
- Height estimated by multiplying successive relative depths
  - accumulated error not compensated
- No ground truth:
  - only GPS altitude
  - at least it demostrates correlation

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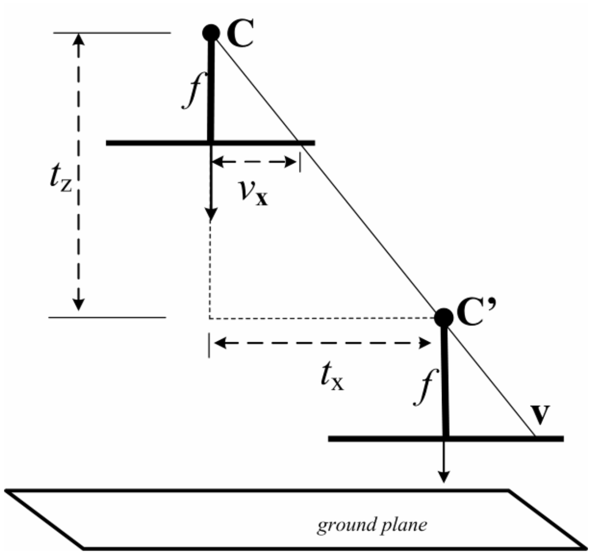
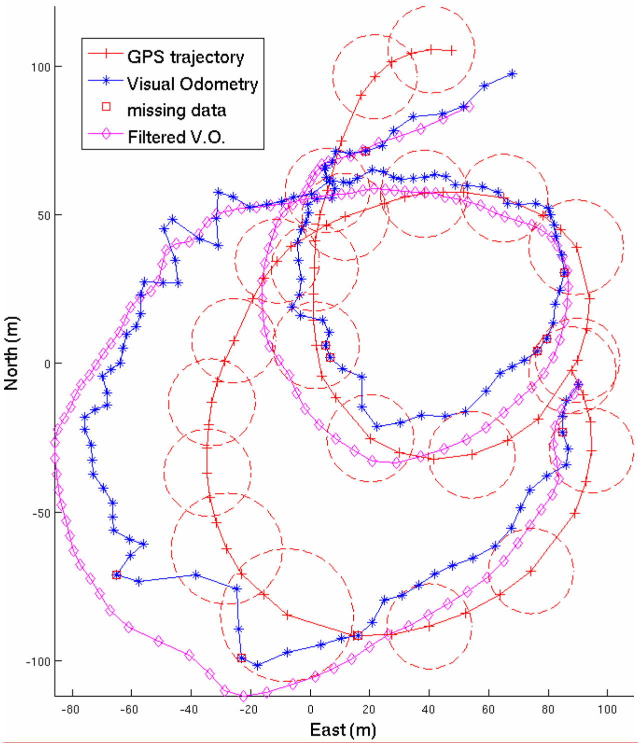
Trajectory estimation for airship UAV

- Altitude is already known
- the FOE is already estimated
  - FOE is the direction of translation
    - albeit without magnitude!
- from magnitude of altitude variation, calculate magnitude of 2D translation
  - similarity of triangles

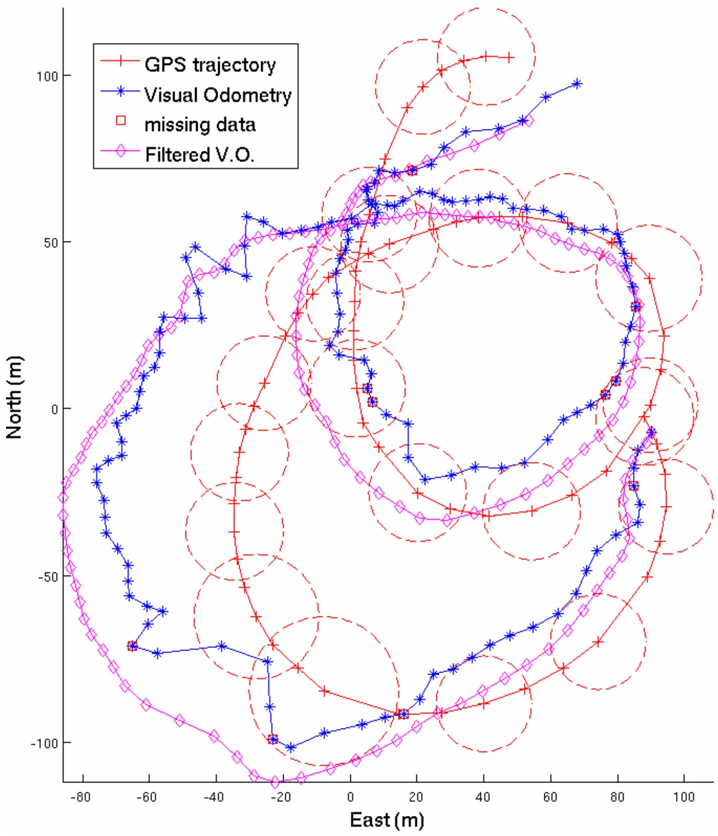


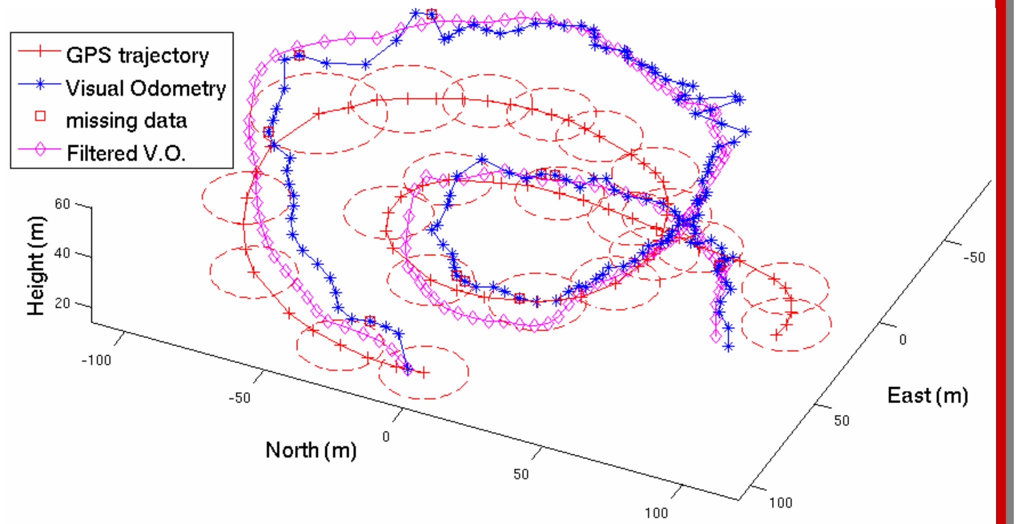
- Result is a sequence of 3D vectors
  - add them to compose trajectory
- Kalman Filter used to get smoother trajectory



Trajectory estimation for airship UAV

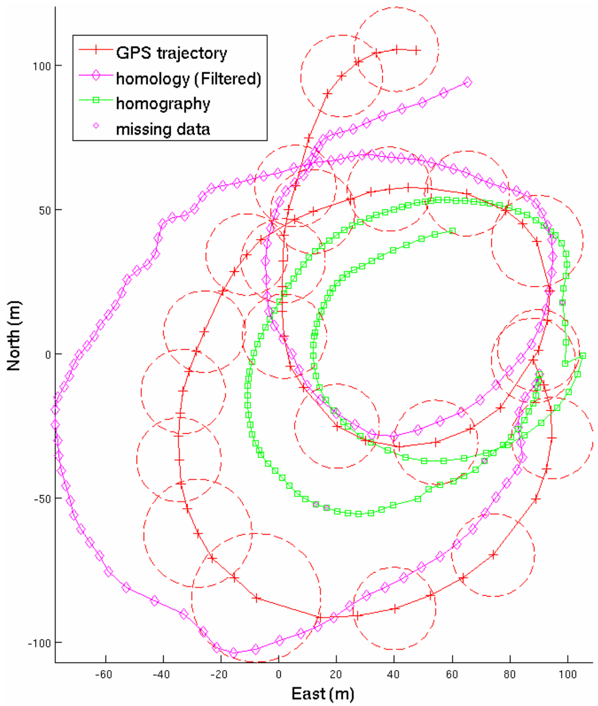
- Estimated Trajectory plotted in 2D and 3D





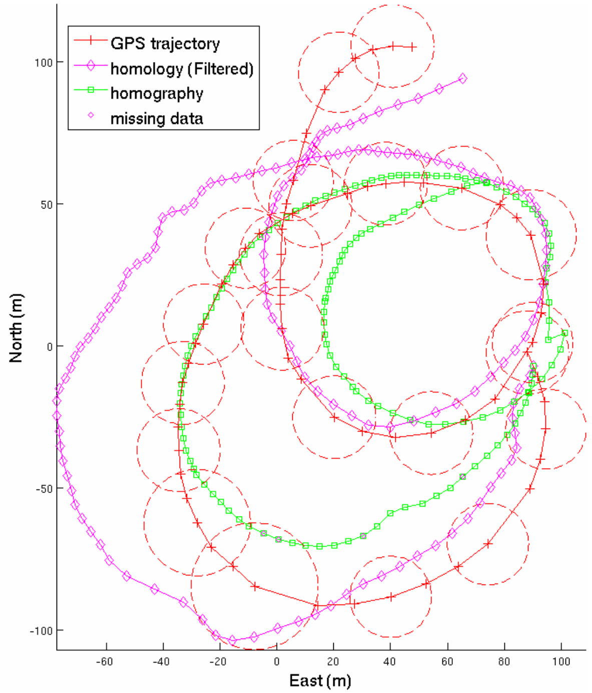
Evaluating the recovered height using the homography

- The usual homography model is used to recover the trajectory (green)
- but the scale is still missing, and depends of a height measurement
  - which is given by the GPS (a) or by the height recovered by the homology model (b)



(a)

GPS



(b)

homology

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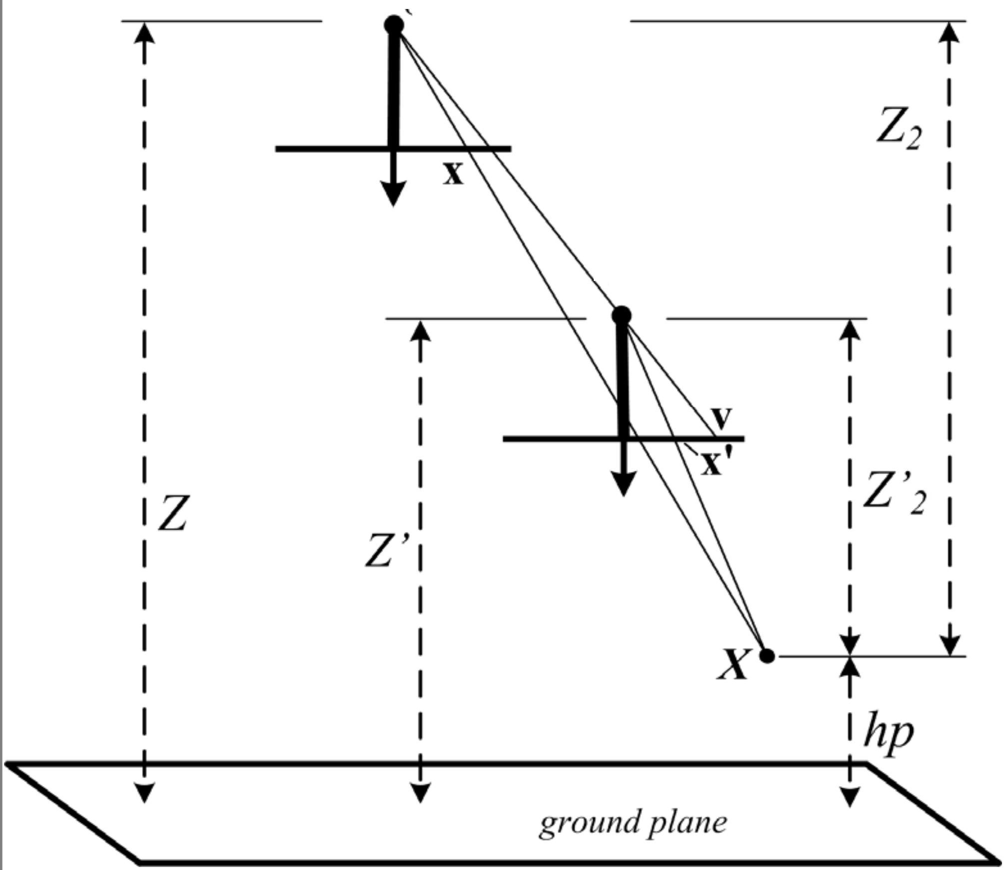
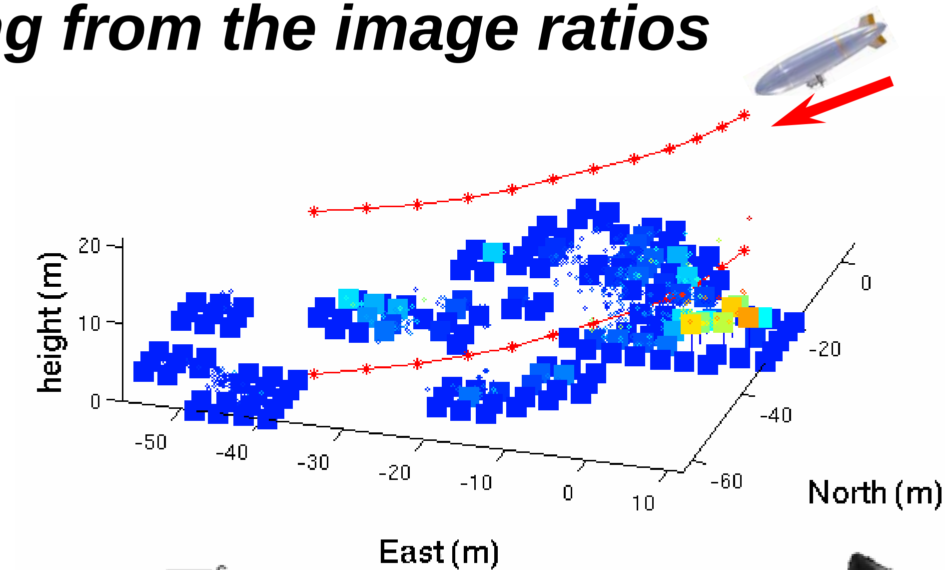
3D Mapping from the image ratios

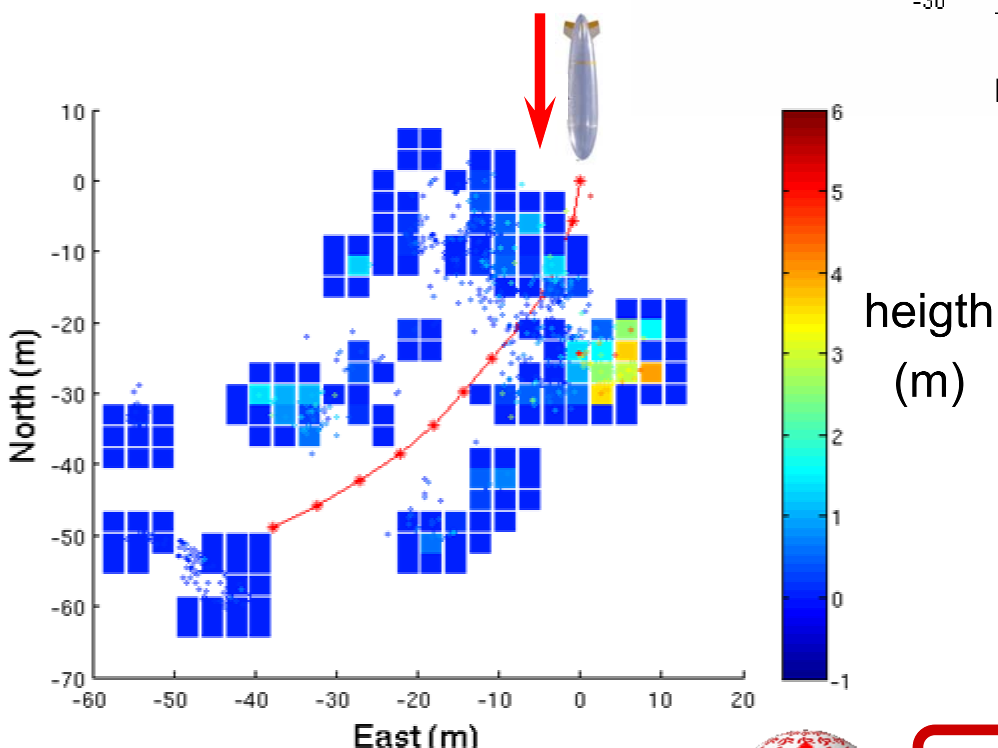


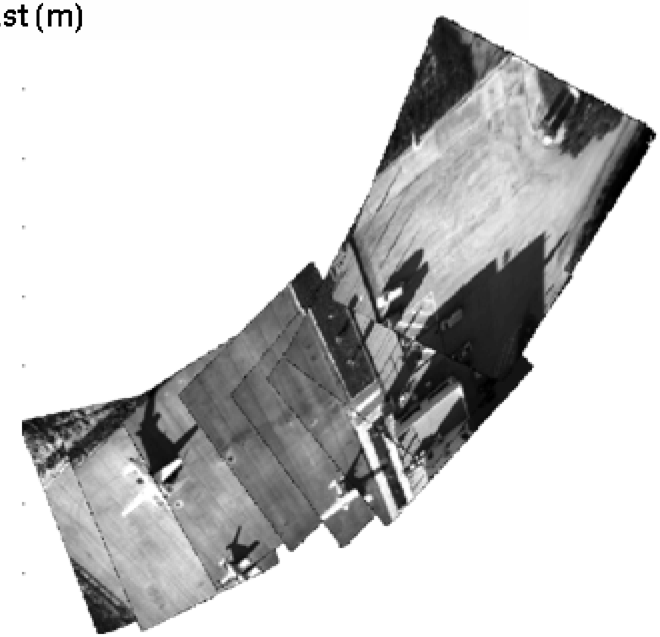
- Every pixel correspondence has a height ratio
  - do not use homologies
  - do not suppose planar area
- With known camera heights, calculates 3D point height
  - for all pixel correspondences

3D Mapping from the image ratios

- Fly over building & planes
  - expect paralax to indicate height
- Place points in a 2D grid
- Estimate each cell height







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Conclusions

- The images are projected into a stabilized plane using inertial data

- The full 3D trajectory of an airship is recovered
  - first the height is recovered as a sequence of ratios
  - then from FOE estimation & camera geometry the 2D translation is recovered

- Comparison: GPS and recovered height used to scale trajectory from homography
  - recovered altitude appears accurate.

- Errors on North-East trajectory are larger
  - probably due to errors on IMU heading and FOE estimation

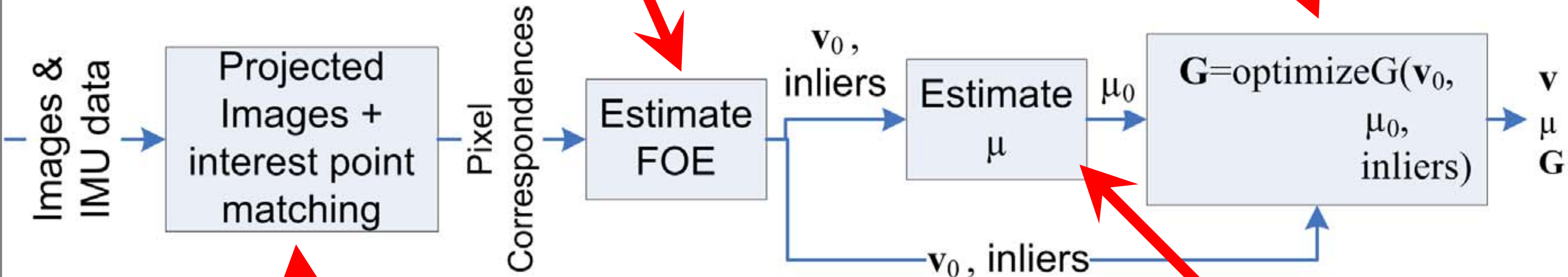
- Vertical and horizontal translational components are separated!
  - easy to include other sensors on the framework

Conclusions

- The homology estimation process can be fast.

Similar as the homography case

FOE estimated from correspondences
  – outliers are eliminated [Chen et al., 2003]



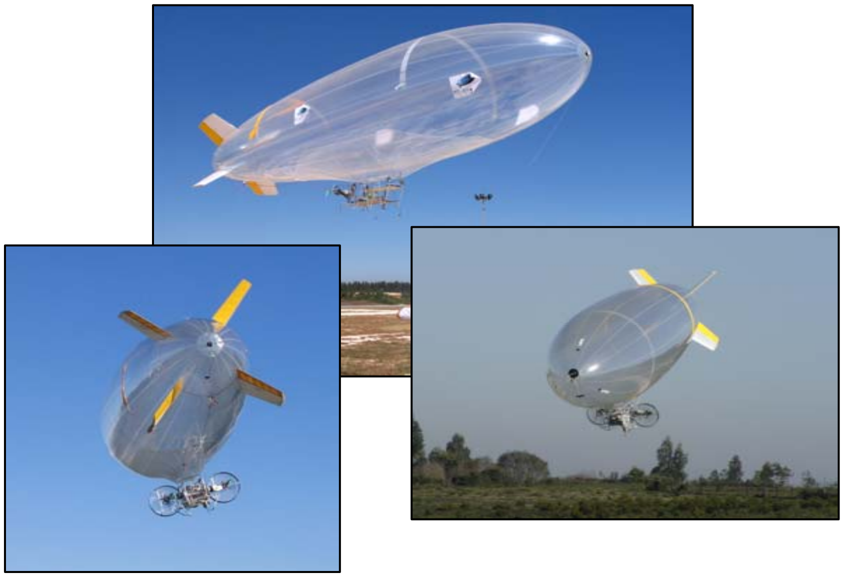
May project only correspondences
  – looses the gains of projecting images

Estimating μ_0 is trivial
  – ratios of image distances

References

- [Bay et al, 2006] Bay, H; Tuytelaars, T.; van Gool, L. "SURF: Speeded Up Robust Features", *Proceedings of the 9th European Conference on Computer Vision*, May 2006
- [Chen et al., 2003] Chen, Z.; Pears, N.; McDermid, J.; Heseltine, T.; "Epipole Estimation under pure camera translation" In *7th Int. Conf. on Digital Image Computing: Techniques and Applications (DICTA)*, pages 849-858, CSIRO Publishing, 2003. Sun, C.; Talbot, H.; Ourselin, S.; Adriaansen, T., editors.
- [Hartley and Zisserman, 2000] Hartley, R. and Zisserman, A. "Multiple View Geometry in computer vision" Cambridge University Press, 2000.
- [Mirisola and Dias, 2007] Mirisola, L; and Dias, J. "Exploiting Inertial Sensing in Mosaicing and Visual Navigation" IFAC Int.Conf. on Intelligent Autonomous Vehicles (IAV07), Toulouse, France, Sep. 2007

THE END



- Rotation compensated:
  - image plane parallel to image plane
    - i.e.: virtual cameras pointing downwards

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