Tracking from a Moving Camera with Attitude Estimates

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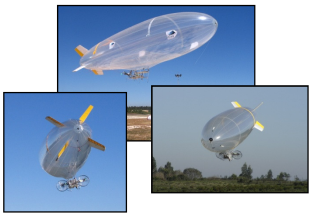
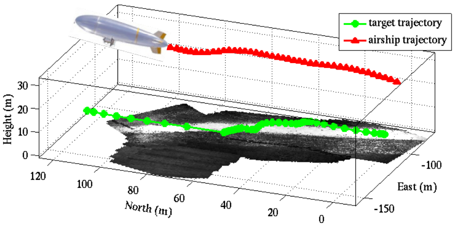


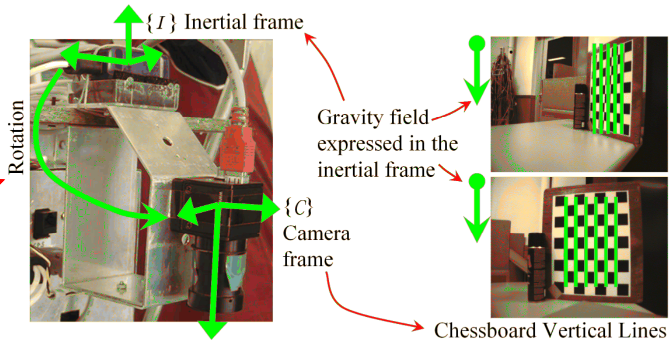


Outline

- **Review**
  - Camera Inertial Calibration
  - Projecting images on a virtual stabilized plane.
  - Relative Pose from two images of a planar patch (homography)
  - Relative Pose with rotation compensated
- Tracking in the ground plane
- Results
  - Tracking with an Airship UAV
  - Tracking people in an urban surveillance context
- Conclusions

Camera-Inertial calibration

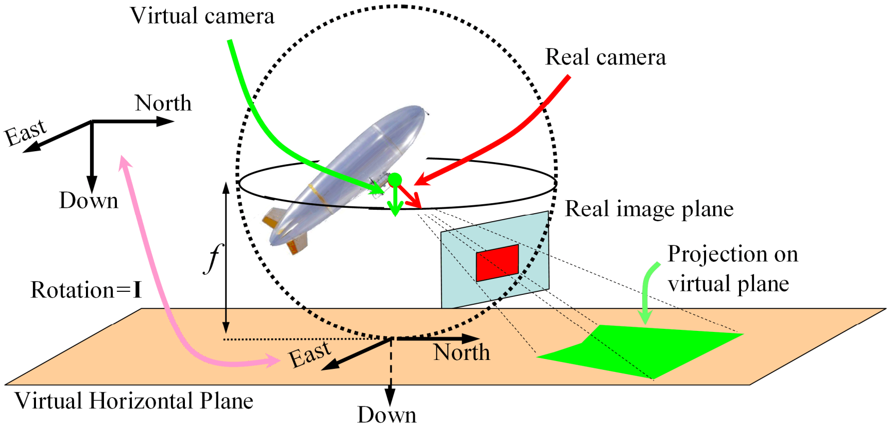
- Camera-Inertial Calibration
  - Rigid mounting
  - IMU: gravity vector
  - CAM: vertical lines
  - Recover rotation between $\{\mathcal{I}\}$ and $\{\mathcal{C}\}$
  - MATLAB Toolkit



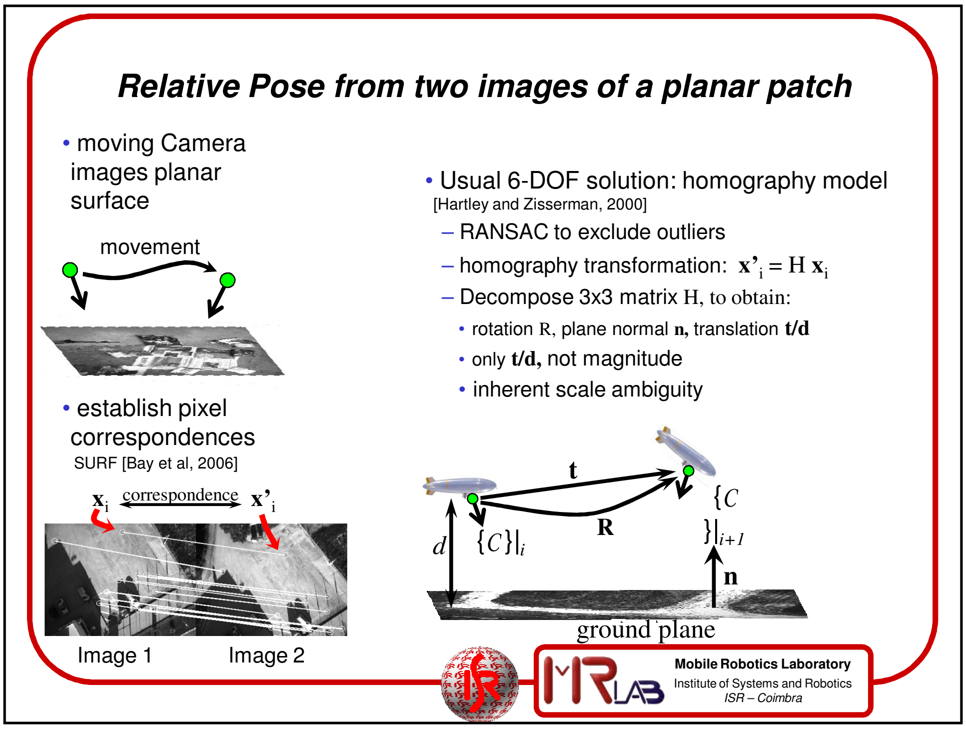
- Conclusion:
  - Inertial system measures camera orientation

[Lobo and Dias, 2007] Lobo, J. and Dias, J. (2007). Relative pose calibration between visual and inertial sensors. *International Journal of Robotics Research*, 26(6):561–575.

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]

- Usual 6-DOF solution: homography model
  [Hartley and Zisserman, 2000]
  - RANSAC to exclude outliers
  - homography transformation: $\mathbf{x'}_i = \mathrm{H}\,\mathbf{x}_i$
  - Decompose 3x3 matrix H, to obtain:
    - rotation R, plane normal **n**, translation **t/d**
    - only **t/d,** not magnitude
    - inherent scale ambiguity

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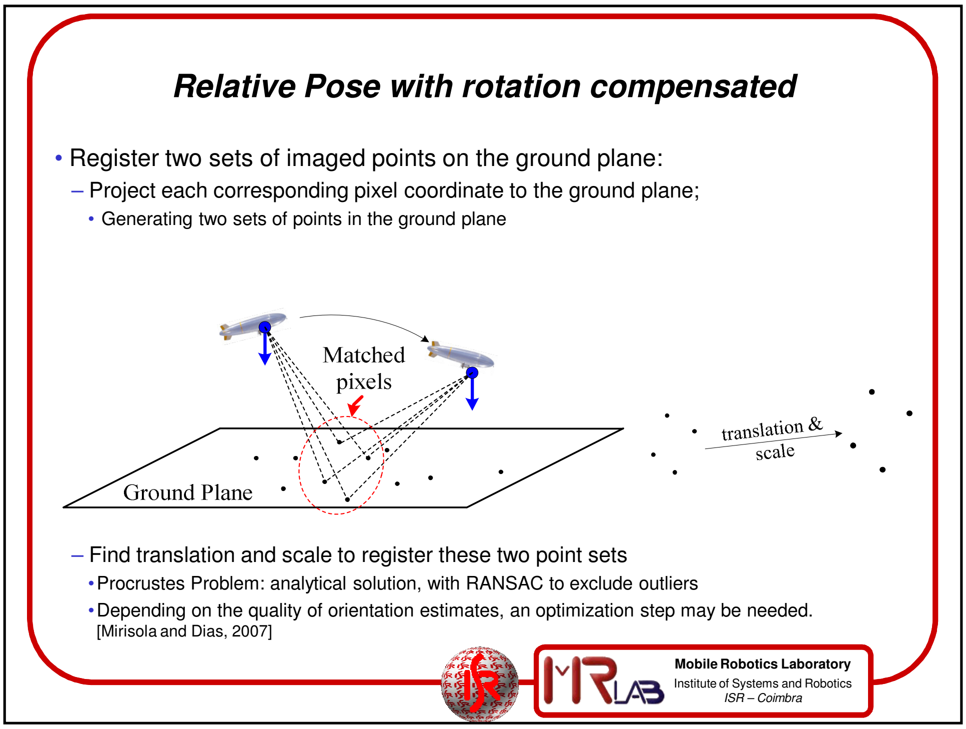

Relative Pose with rotation compensated

- Register two sets of imaged points on the ground plane:
  - Project each corresponding pixel coordinate to the ground plane;
    - Generating two sets of points in the ground plane

  - Find translation and scale to register these two point sets
    - Procrustes Problem: analytical solution, with RANSAC to exclude outliers
    - Depending on the quality of orientation estimates, an optimization step may be needed.
      [Mirisola and Dias, 2007]

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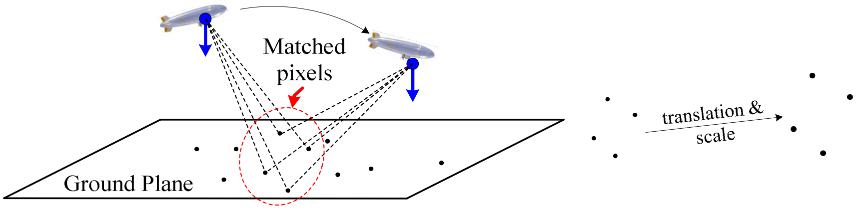
Relative Pose with rotation compensated

- Kalman Filter for airship trajectory:
  - Filter state: position, velocity, acceleration
    - translation vectors interpreted as a velocity measurement
  - Standard prediction models [Bar-Shalom 2000]
    - e.g. Wiener Process acceleration
    - Constant velocity model not enough for airship trajectory

$$\begin{bmatrix} x \\ \dot{x} \\ \ddot{x} \end{bmatrix}$$



- Visual Odometry more accurate than with usual homography model
  - These gains translate into more accurate tracking.
  - Scale ambiguity remains: translation depends of the camera height.

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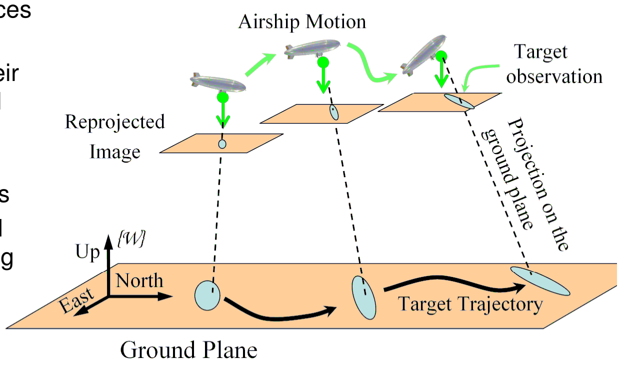
Tracking on the ground plane

- Target Observations in the reprojected virtual images
  - projected onto the ground plane by the Unscented Transform [Julier and Uhlmann, 1997]
  - Taking into account uncertainty in the airship position and orientation [Merino et al., 2005]

- Anisotropic covariances for observations
- Observations and their covariances in actual metric units
- Filter parameters defined in actual units
- More meaningful and accurate than tracking in image space



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Tracking on the ground plane

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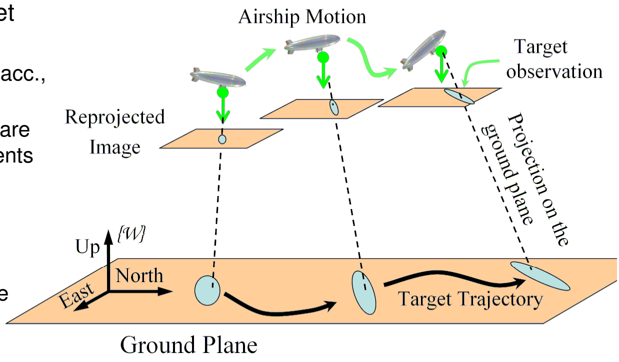
- Kalman Filter for target trajectory
  - again position, vel., acc., but now 2D
  - target observations are position measurements w/ anisotropic covariance
  - Target missing in some frames
  - Lowpass filter before KF input



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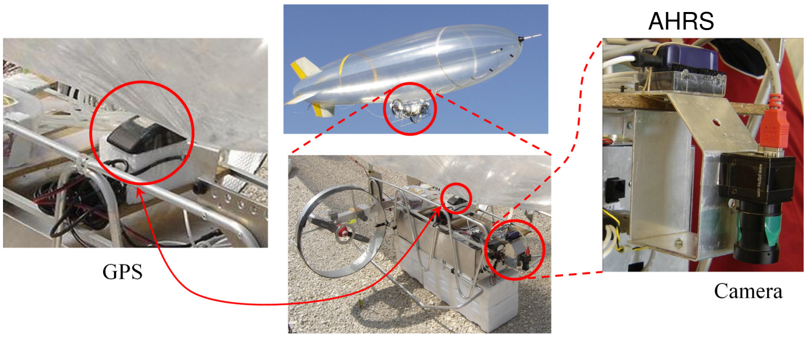
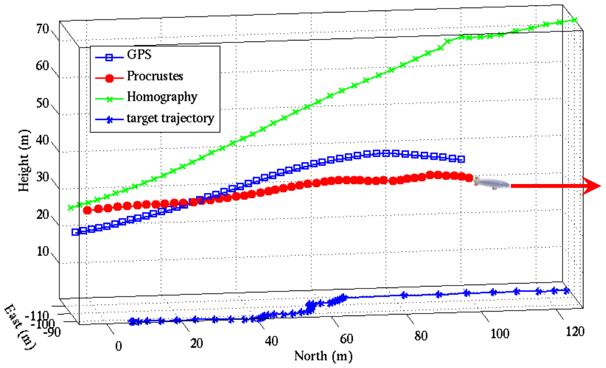
Tracking with an Airship UAV

- AHRS & Camera mounted on remotely controlled airship, with GPS



Tracking with an Airship UAV:
Recovered Trajectories for Airship & Target



- Divergence of airship trajectory from GPS much slower with rotation-compensated model.
- Scale ambiguity: errors in height estimation imply in wrong translation magnitude next time.

- Visual Odometry height initialized by imaging large object of known dimensions in the ground
  - and estimating height from its dimensions on the image and camera intrinsic parameters

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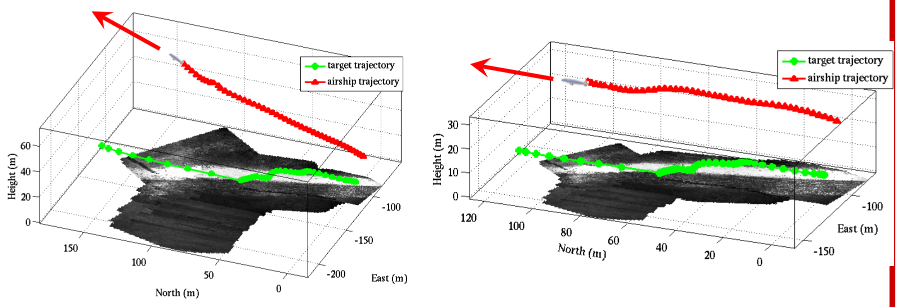
Tracking with an Airship UAV:
Comparing pure translation and homography model



Homography model

Pure Translation model

- Note the difference of scale between both graphs.

- Airship drawn close to real scale (9 m long)

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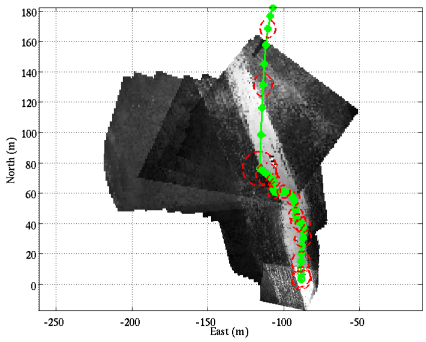
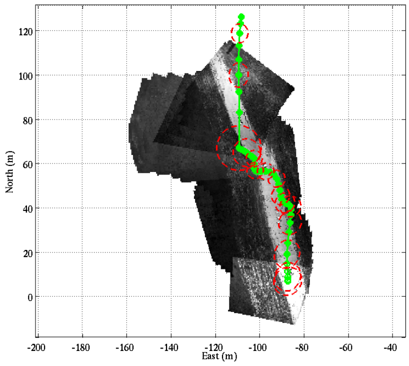
Comparing pure translation and homography model



Homography model

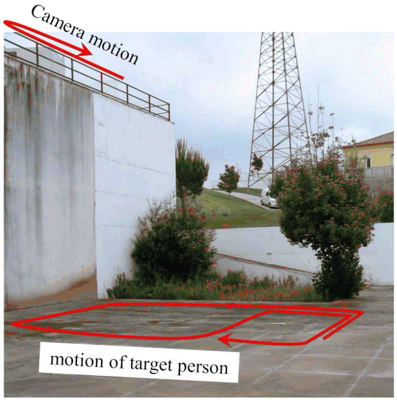
- A 2D view of the same data

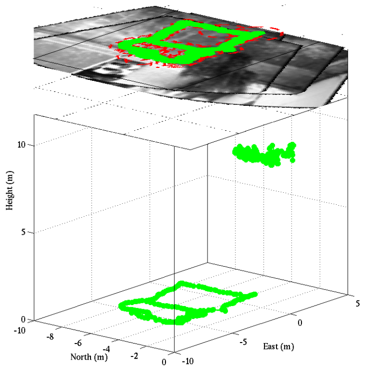


Pure Translation model

Tracking people in an urban surveillance context

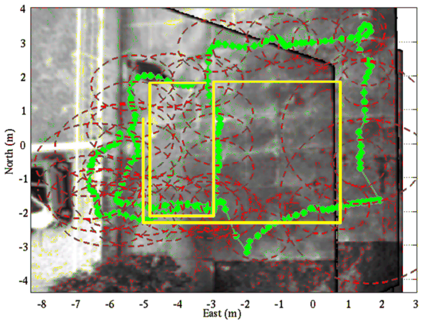
- A moving camera tracks people moving on a lower level.
  - here it was moved by hand, but the camera might be mounted on a mobile robot.
  - to extend the coverage of static cameras or focus the attention after a detected event



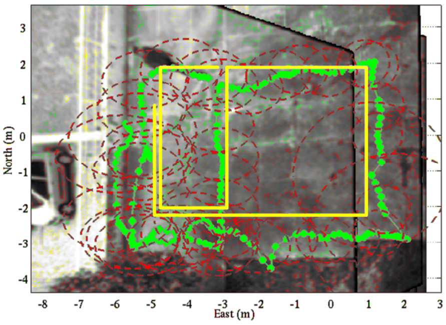


Tracking people in an urban surveillance context

- yellow straight lines are ground truth: person walked on lines between tiles
- red ellipses indicate 1 standard deviation.
- target was not observed for some frames at the bottom right



Homography model



Pure Translation model

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Conclusions

- Summary
  - The images are projected into a stabilized plane using AHRS orientation data
  - The full 3D camera trajectory is recovered
  - Target observations are projected on the ground plane (Unscented Transform)
  - Target is tracked in 2D coordinates
- Airship and urban surveillance scenarios

- Pure translation model
  - better accuracy in camera trajectory
    - implies in more accurate target trajectory
  - Visual Odometry may be fused with other localization sensors [Mirisola and Dias, 2008]
    - GPS (airship), wheel odometry or beacon-based localization (urban surveillance)

- Tracking in the ground plane
  - Exploits the actual problem geometry
  - Computation performed in actual metric units and coordinate systems
    - Filter parameters also set in actual, meaningful units.
    - Avoids projective distortion and pixel units of image space tracking

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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
- [Hartley and Zisserman, 2000] Hartley, R. and Zisserman, A. “Multiple View Geometry in computer vision” Cambridge University Press, 2000.
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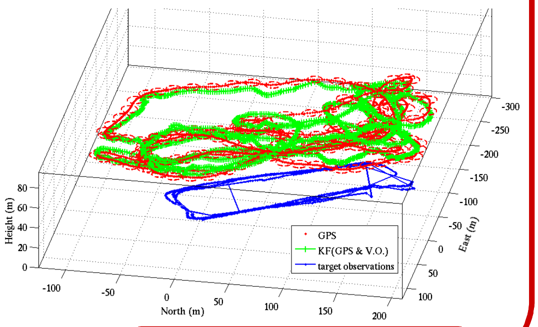
- [Merino et al., 2005] Merino, L., Caballero, F., de Dios, J., and Ollero, A. (2005). “Cooperative fire detection using unmanned aerial vehicles.” In *IEEE International Conference on Robotics and Automation*, pp.1896–1901, Barcelona, Spain.
- [Mirisola and Dias, 2007] Mirisola, L; and Dias, J. “Visual Odometry and 3D Mapping from rotation-compensated imagery” *IEEE Int. Conf. on Intelligent Robots and Systems (IROS07)*, November, San Diego, CA, USA.
- [Mirisola and Dias, 2008] Mirisola, L; and Dias, J. “Tracking a Moving Target from a Moving Camera with Rotation-Compensated Imagery” Chapter in *Intelligent Aerial Vehicles*, I-Tech Publishers, Vienna, Austria.

THE END

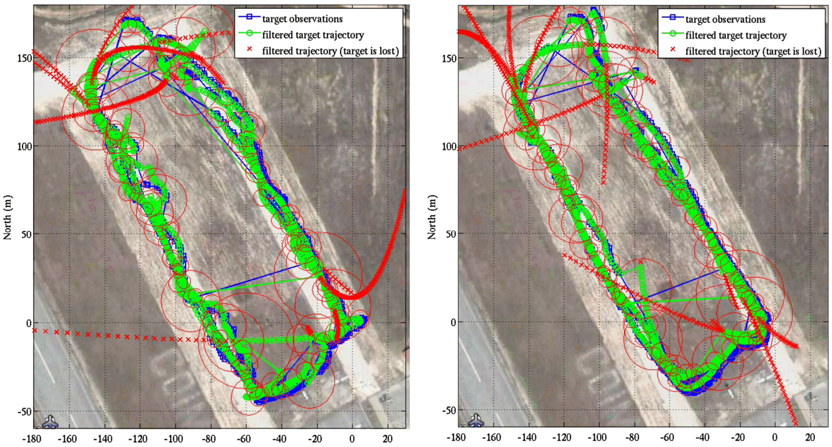
Tracking with Airship: fusing Visual Odometry and GPS

- GPS position fixes are fused with Visual Odometry by the same KF
  - GPS supplies position measurements
  - Translation vectors from Visual Odometry are velocity measurements
  - The fused trajectory does not diverge due to GPS
  - and it is locally improved due to Visual Odometry

- Long term tracking with improved trajectory
- target (car) moves in a loop while airship flies over it.
- straight lines on target trajectory indicate missing observations
- See [Mirisola and Dias, 2008]



Tracking with Airship: fusing Visual Odometry and GPS



GPS only

Fused GPS & V.Odom

x: target position st. dev. > 30m due to lack of observations.

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