Lakeside Labs
SELF-ORGANIZING NETWORKED SYSTEMS

RESEARCH | DAYS
20 | 13

Klagenfurt, Austria, 8-10.7.2013

Small Flying Robots
Design and Visual Navigation

Roland Siegwart
Autonomous Systems Lab
ETH Zurich
www.asl.ethz.ch

Autonomous Systems Lab

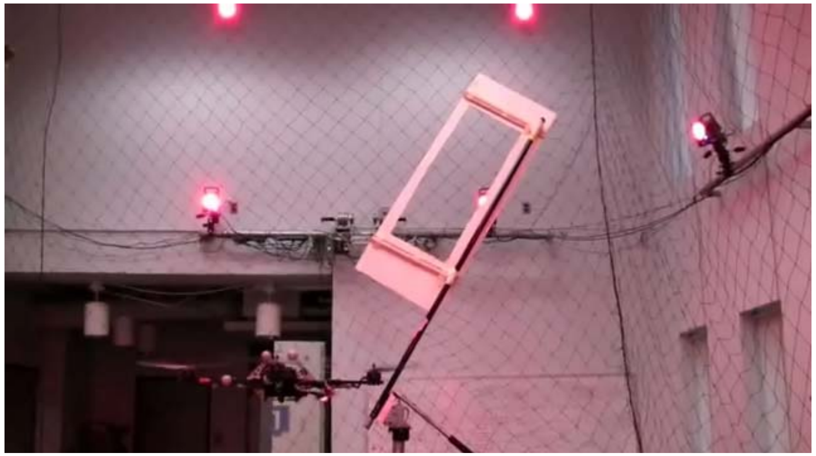
ETH zürich

Co-axial and Multicopter UAVs

OS4 - 2003
70 cm
650 g

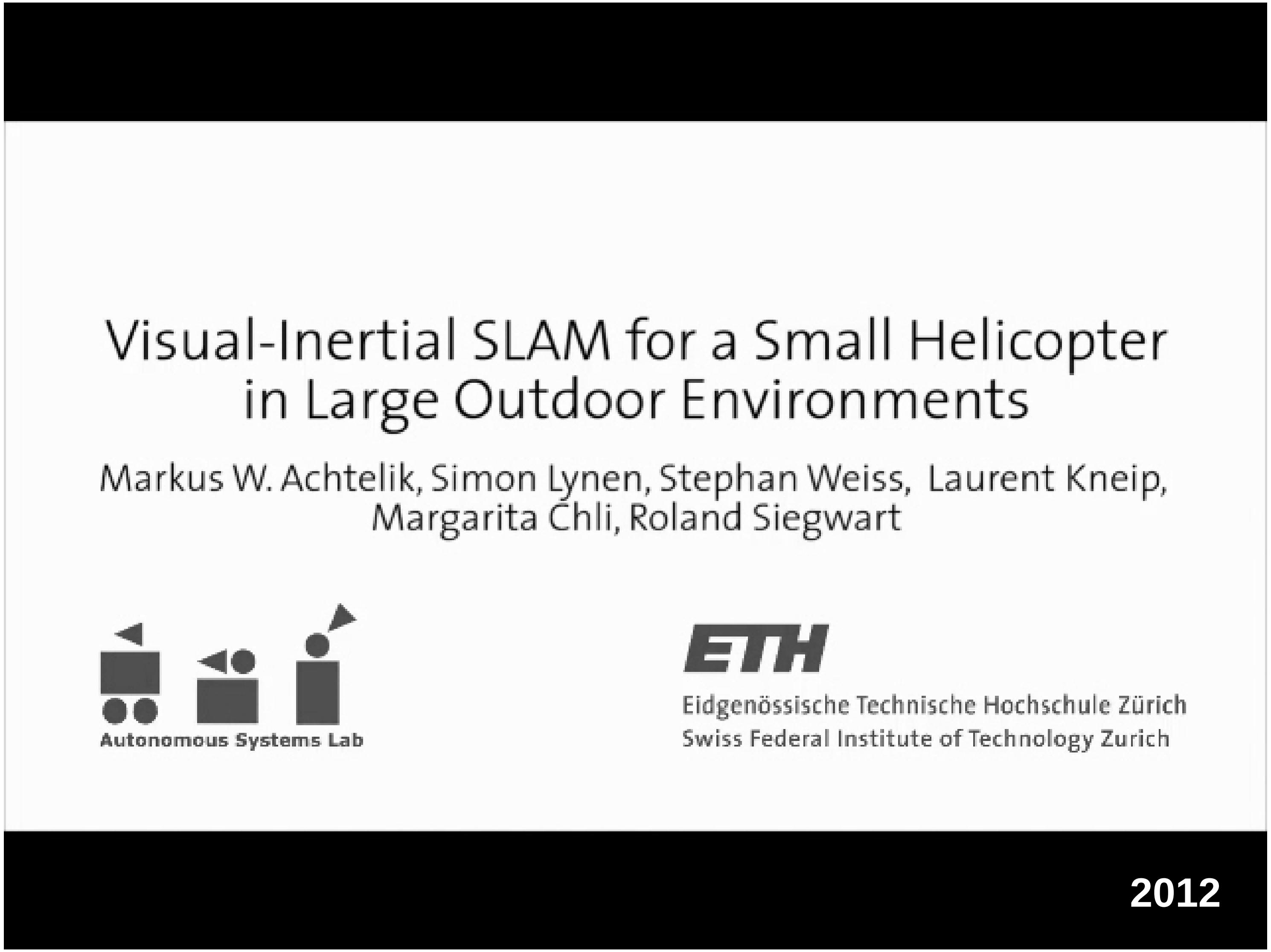
CoaX – 2005
30 cm
200 g

Vijay Kumar et al.
University of Pennsylvania



sFly – Swarm of micro Flying robots with feature based visual navigation

www.sfly.ethz.ch/



Vision-based MAV navigation

- Autonomous vision-based flight is feasible today
- Similar framework used by NASA JPL, UPenn, MIT, TUM,...

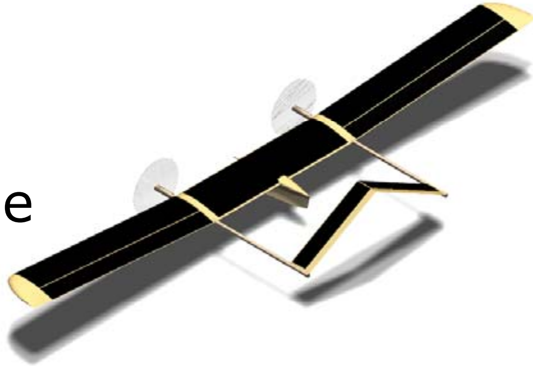
However, ...

... there are still many challenges

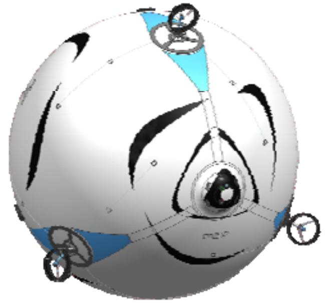
- Regulations
  - Risk / Reliability / Consequences of failure
- Operations
  - User-friendly » Human-machine interfaces
- Autonomy
  - Flight duration » other flight concepts
  - Collision avoidance » dense maps
  - Robustness » visual features
  - Localization / SLAM » loosely coupled filter » continuous-time estimation
  - On-board calculation » algorithmic efficiency » specific hardware

Flying Concepts

- Helicopters:
  - < 20 minutes
  - Highly dynamic and agility



- Fixed Wing Airplanes:
  - > some hours; continuous flights possible
  - Non-holonomic constraints



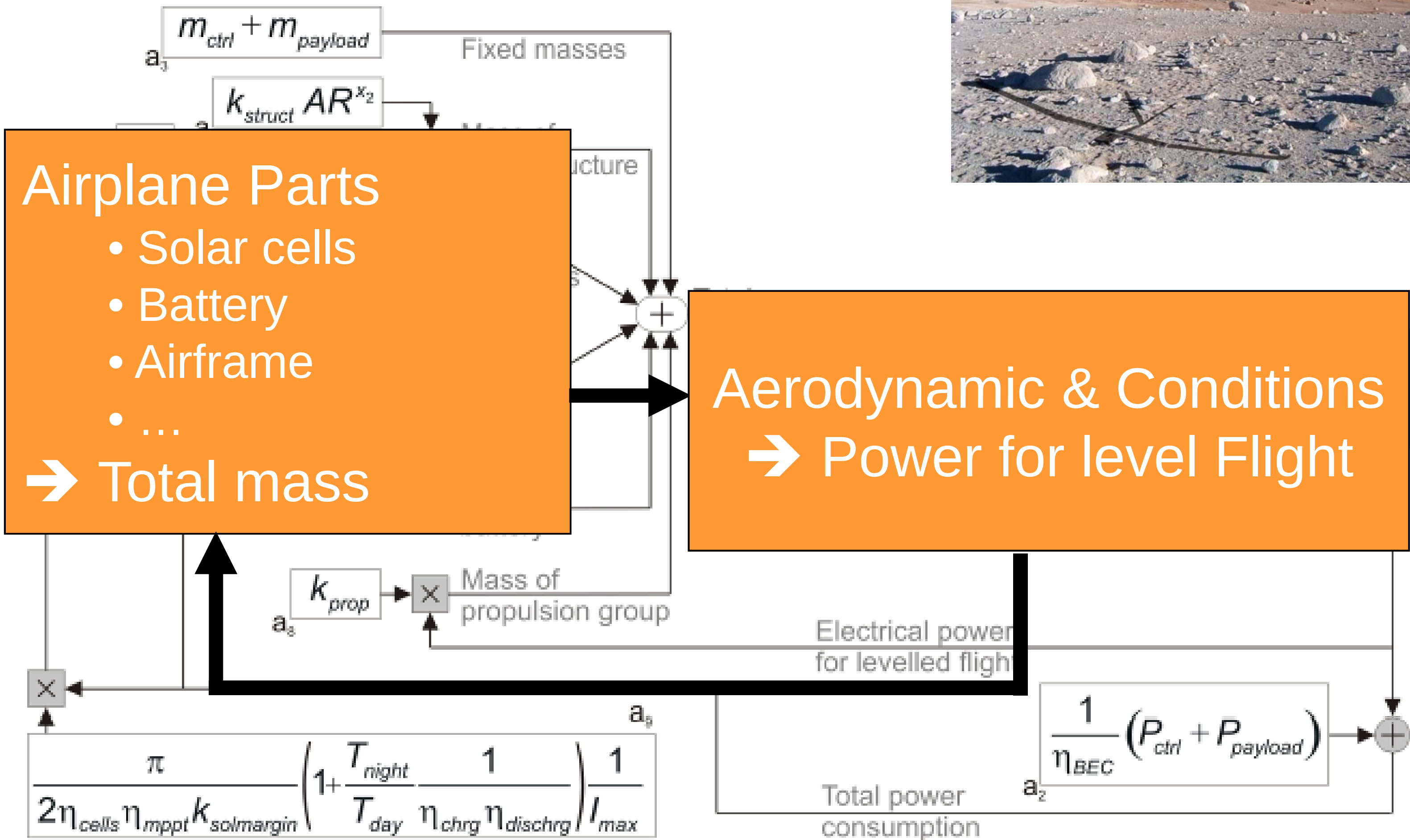
- Blimp: lighter-than-air
  - > some hours (dependent on wind conditions);
  - Sensitive to wind
  - Large size (dependent on payload)

- Flapping wings
  - < 20 minutes; gliding mode possible
  - Non-holonomic constraints
  - Complex mechanics

Festo BionicOpter

Solar Airplane for Continuous Operation
Design Methodology

- Based on Mass & Power Balance
  - Need for precise scaling laws (mass models)

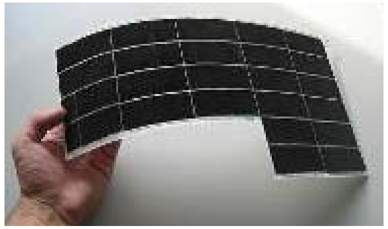


Solar Airplane
SkySailor – Ready for Continuous Operation

- Continuous flight successfully demonstration on

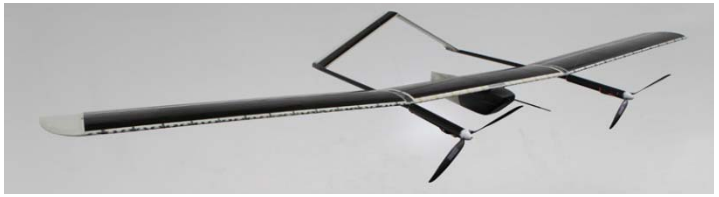
June 20 to 21, 2008
- 27 hours flight

- Main Characteristics
  - 3.2 m wing span
  - 2.4 kg total weight
  - 1.2 kg of battery
  - $P_{Leveled}$ ~ 12W (without payload)
  - Very stable, even at high speeds
  - Maximum power point
    - 91-92 % efficiency
    - 7 grams



senseSoar and AtlantikSolar

- Solar powered fixed wing airplanes:
  - Long duration / continuous flights



senseSoar

Wingspan:	3 m
Wing area:	0.725 m2
Peak Solar power	140 W
Power Consumption	50 W
Masses:	
◦ Overall:	3.72 kg
◦ Batteries:	1.89 kg
Nominal Speed	10 m/s

- Sensors
  - Air speed
  - IMU
  - GPS
  - Camera
  - **IR camera**

AtlantikSolar

Wingspan:	5.64 m
Solar area:	1.5 m2
Peak Solar power	280 W
Power Consumption	40 W
Masses:	
◦ Overall:	6.2 kg
◦ Batteries:	1.89 kg
Nominal Speed	10 m/s

- Sensors
  - Air speed
  - IMU
  - GPS
  - Camera

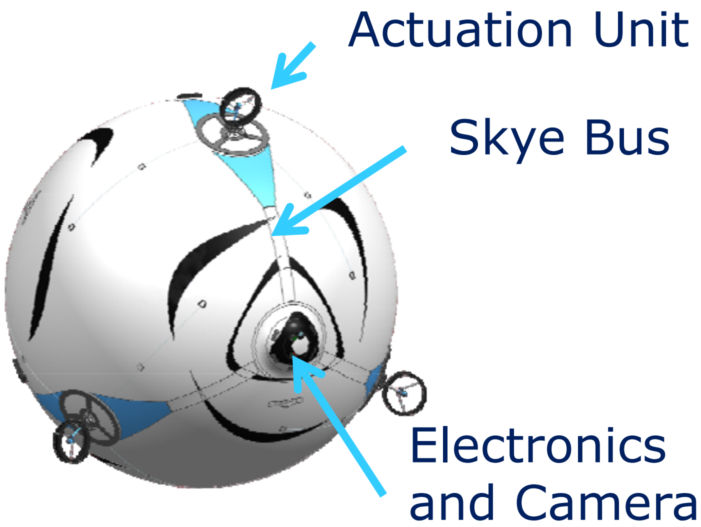
Atlantik-Solar UAV

ETH zürich

skye an omnidirectional, spherical aircraft

overview

www.projectskye.ch/



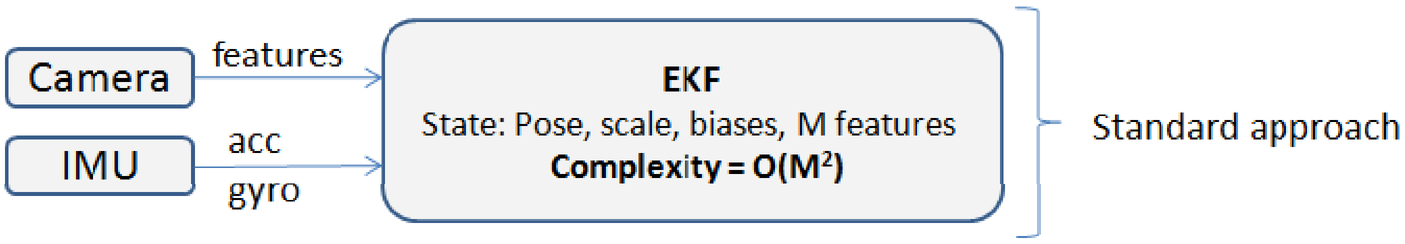
Total Weight	9.818 kg
Actuation Units (4x)	2.737 kg
Electronics and Power	2.706 kg
Hull	3.650 kg
Pressure Elements	Ca. 0.150 Kg

Buoyancy	Ca. 10 kg
Diameter	Ca. 2.7 m
Volume	Ca. 10 m^3

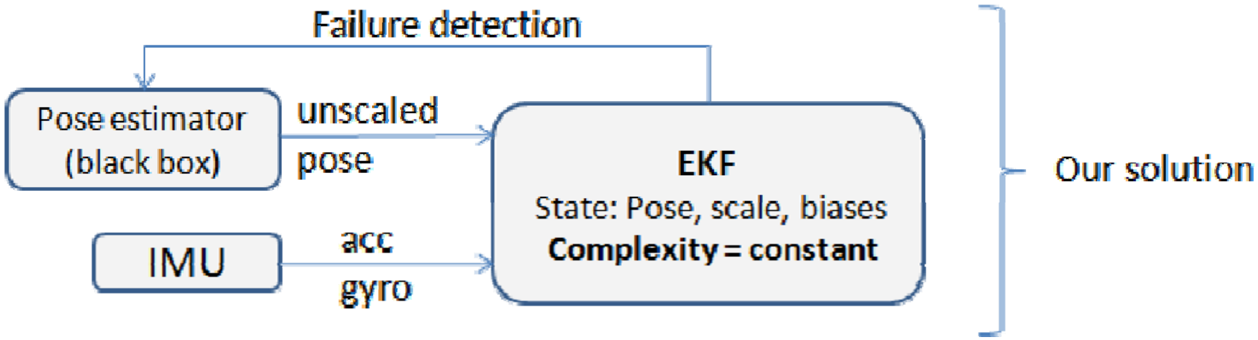
Disney Research, Zurich ETH zürich

EKF based visual-inertial fusion

- A standard, tightly-coupled approach:



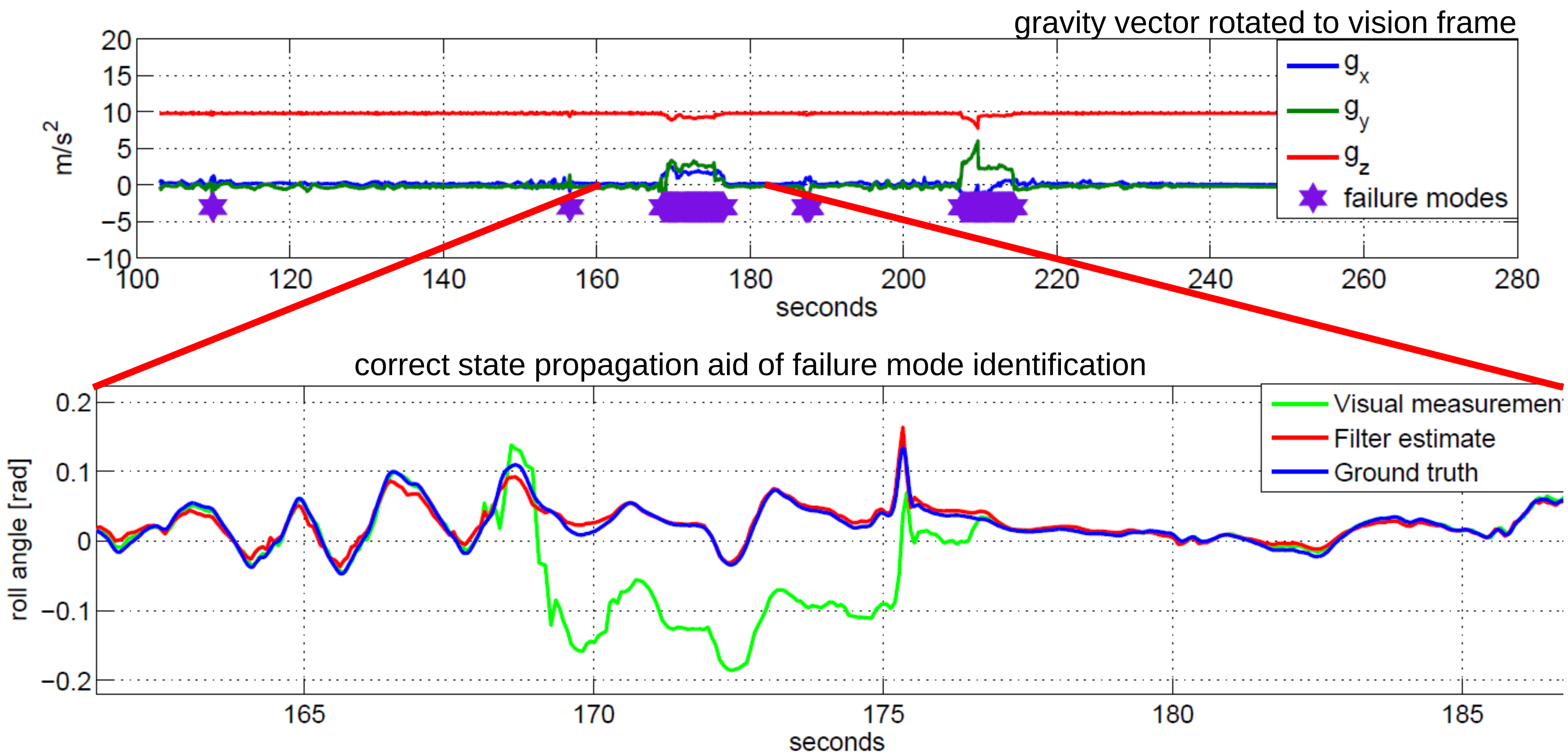
- **Loosely coupled** filter based approach:
  - Pose estimation filter has **constant complexity**
  - Any (visual) pose can be used – pose comes from black box



S. Weiss, M. W. Achtelik, S. Lynen, M. Achtelik, L.Kneip, M. Chli and R. Siegwart
JFR 2011, ICRA 2011, ICRA 2012, IROS 2012, RSS 2012, ICRA 2013, JFR 2013

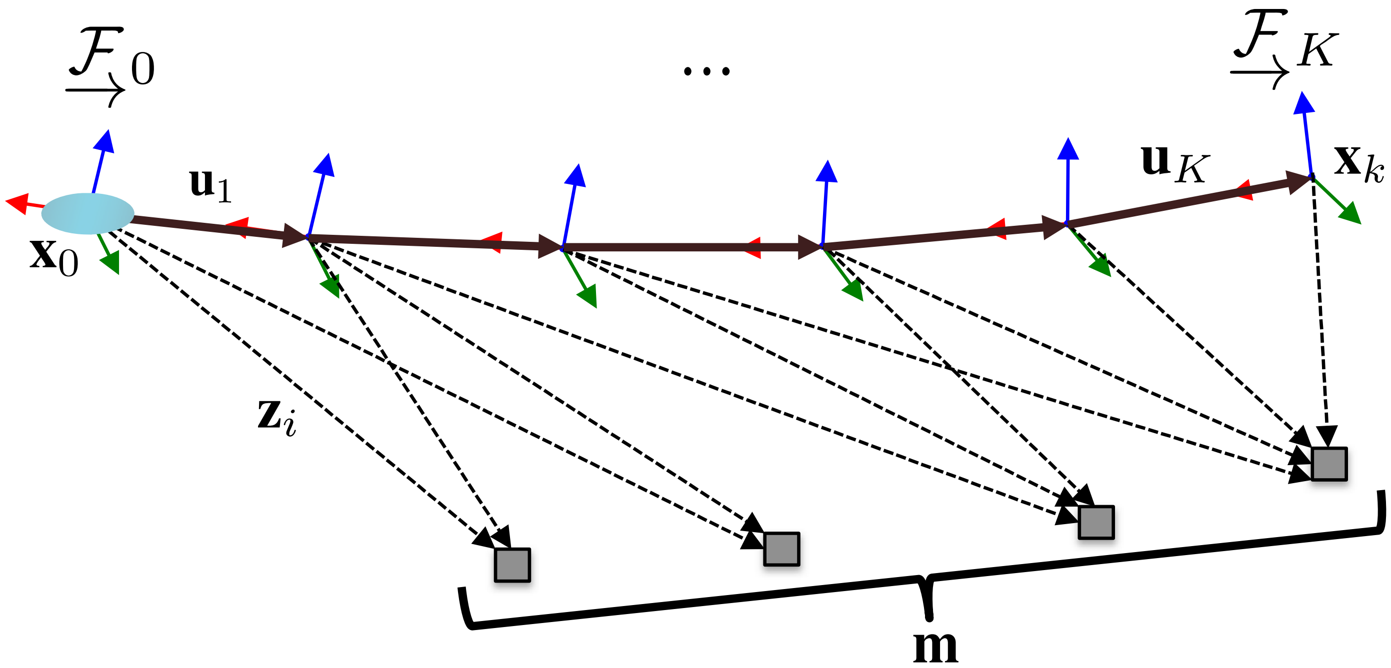
Vision – IMU Based State Estimation

- Use discontinuities in angular drift q_V^W to detect failure modes of the visual black box



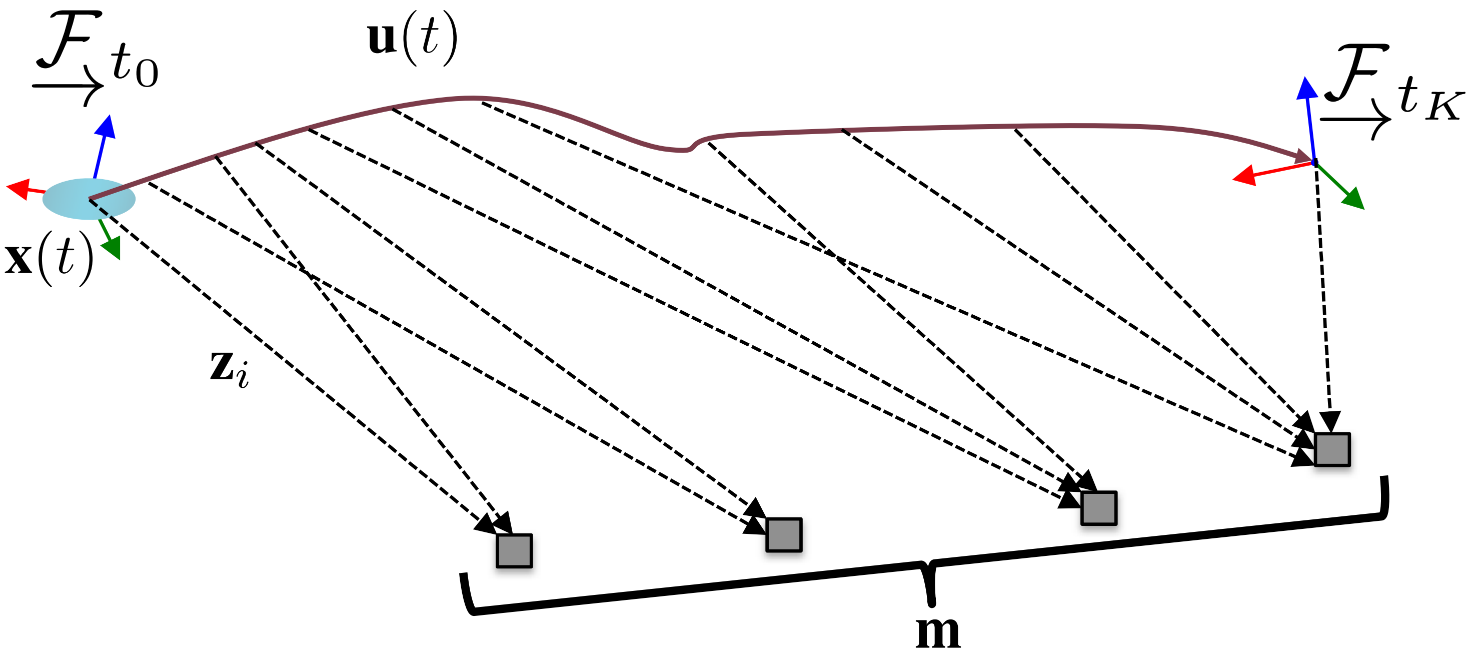
Fusion at any time | Continuous-time state estimation

- Formulation of the state estimation at discrete time instances



Fusion at any time | Continuous-time state estimation

- Formulation of the state estimation in continuous time

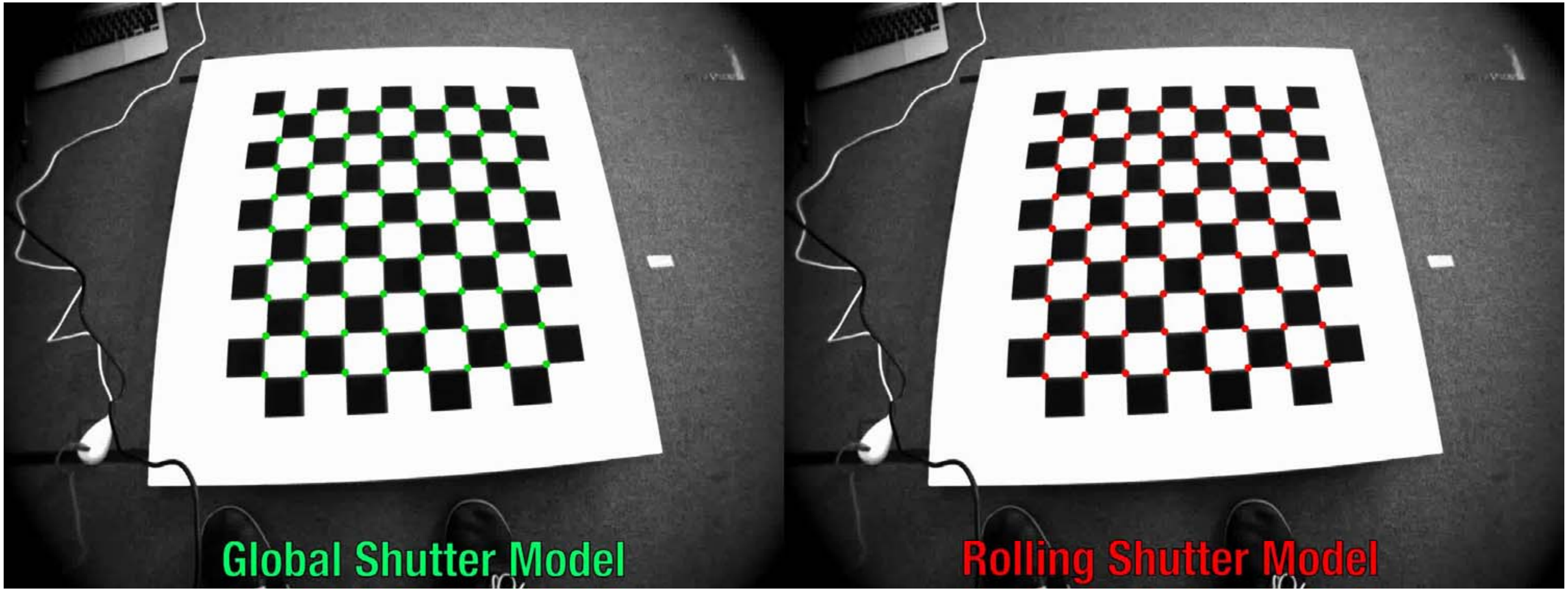


- Well-known parametric representations, such as B-splines, make the problem tractable

$$\mathbf{\Phi}(t) := \begin{bmatrix} \phi_1(t) & \dots & \phi_M(t) \end{bmatrix}, \quad \mathbf{x}(t) := \mathbf{\Phi}(t)\mathbf{c}$$

Continuous-time state estimation | elimination of distrortions due to rolling shutter camera

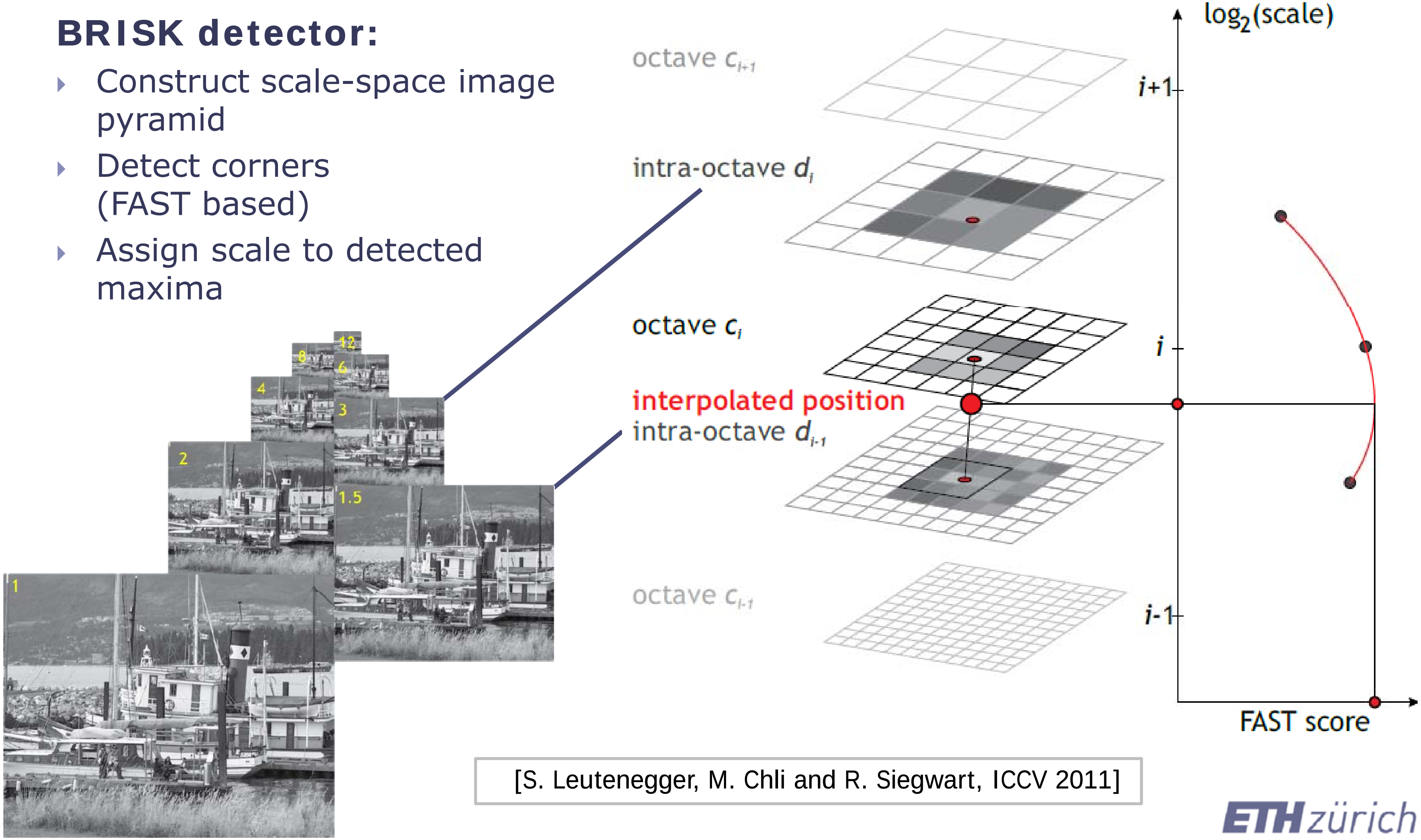
- Application 1: Rolling Shutter Camera Calibration



BRISK: Binary Rotation Invariant Scalable Keypoints

BRISK detector:

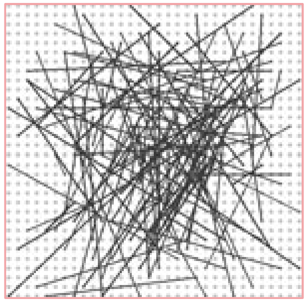
- Construct scale-space image pyramid
- Detect corners (FAST based)
- Assign scale to detected maxima



[S. Leutenegger, M. Chli and R. Siegwart, ICCV 2011]

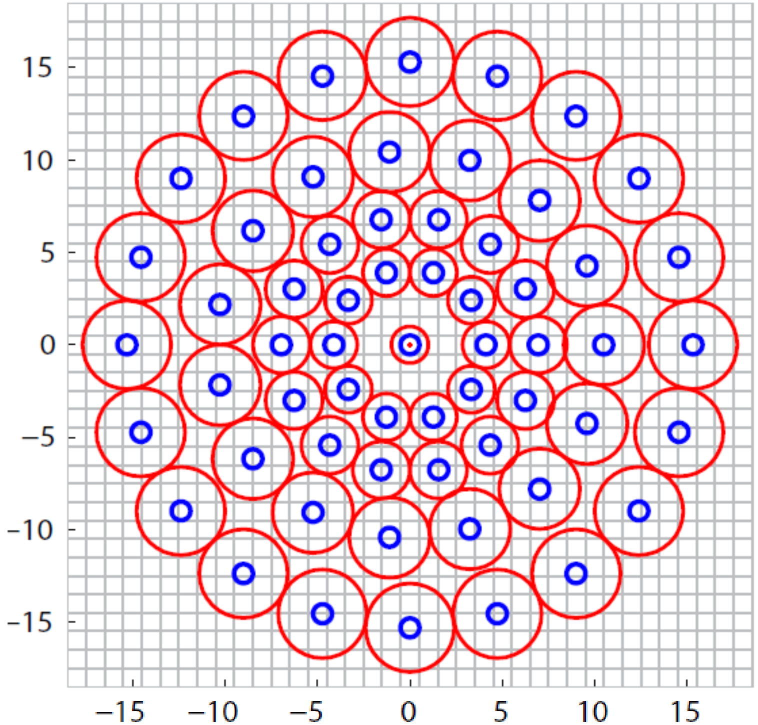
BRISK: Binary Rotation Invariant Scalable Keypoints

BRIEF pattern for intensity pair samples – generated **randomly** [Calonder et al., 2010]



BRISK pattern:

- Use pattern to access image values in a keypoint neighborhood
- Red circles: size of smoothing kernel applied.
- Blue circles: sample pixel values
- Scaled and rotated versions stored in a look-up table



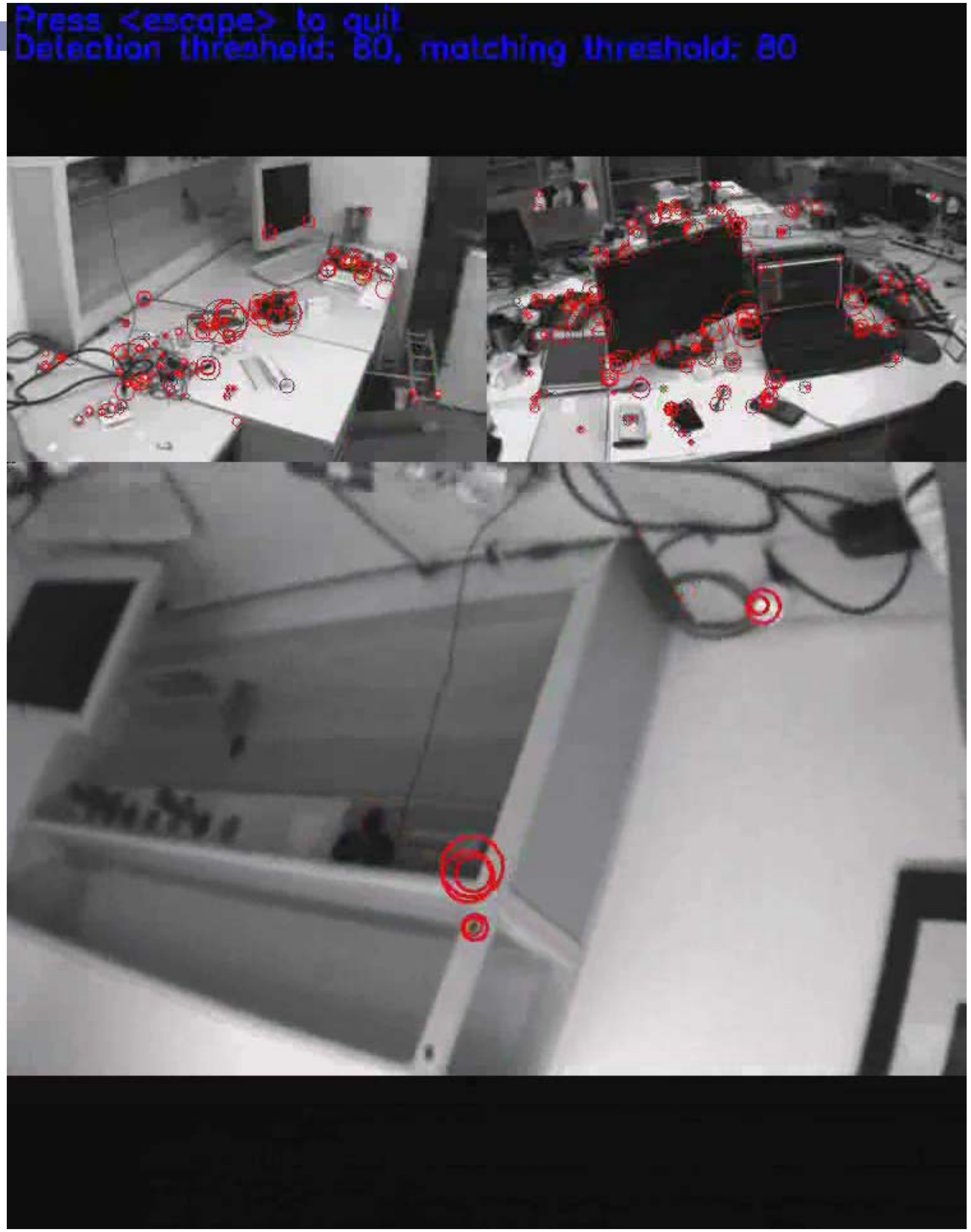
BRISK sampling pattern

- Pairwise intensity comparisons used for orientation assignment
- **Binary Descriptor**: a concatenation of pairwise comparison results

BRISK in action

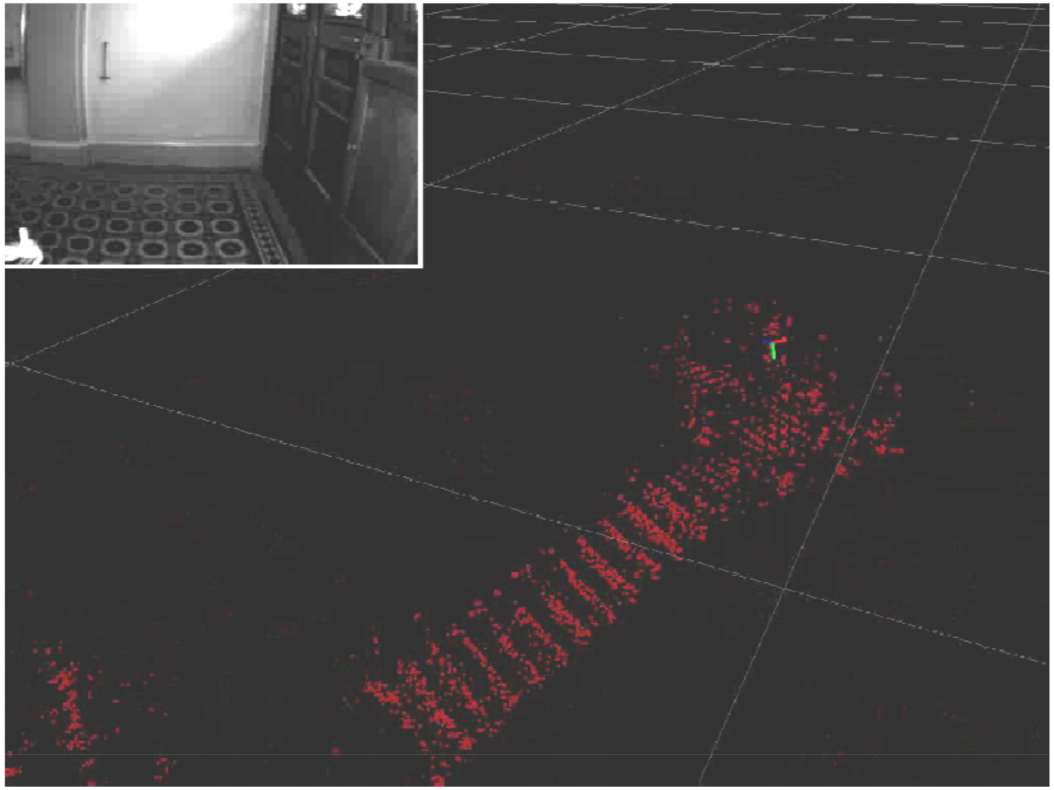
- Precision-Recall: comparable to SIFT and SURF
- Detection and description ~**10x faster than SURF**
- Very fast matching using Hamming distance
- Open-source, BSD license
- Part of latest OpenCV

[S. Leutenegger, M. Chli and R. Siegwart, ICCV 2011]



Stereo Vision based Navigation with UAVs

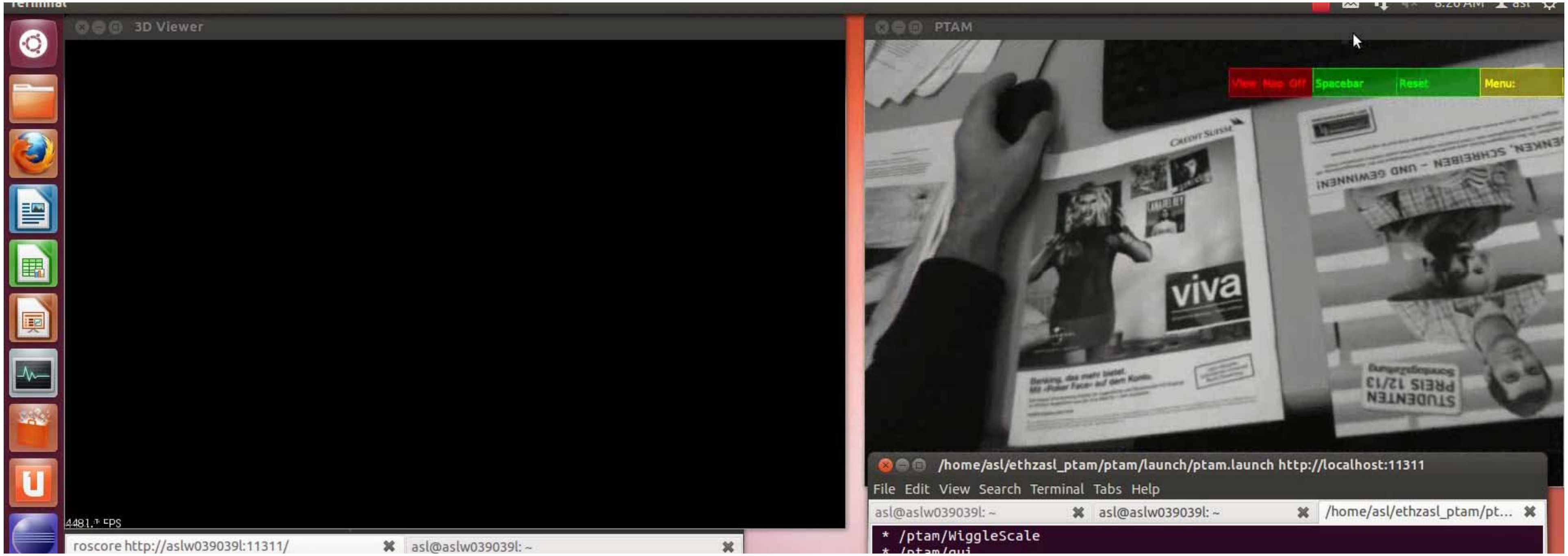
- Feature based visual 3D mapping through transformation chaining (vision & IMU)
- vSLAM with BRIEF / BRISK features



Feature Base Mapping
Sparse

Live, denser maps for MAV navigation

- Naïve stitching of **disparity maps from a single camera**
- Use **visual features** selected for SLAM tracking as "**support points**" to "pin" the disparity maps to the scene structure
- Outlook: perform live dense mapping from a MAV



Take-Home Message

- Long duration flights are possible with fixed-wing solar airplanes and blimps.
- Recent results in feature based visual navigation with micro air vehicles show high potential.
- By improving features and estimation techniques, more robustness is in reach.