Fusion of Distributed Perception in Collaborative Visual-SLAM Approaches on Mini-UAVs

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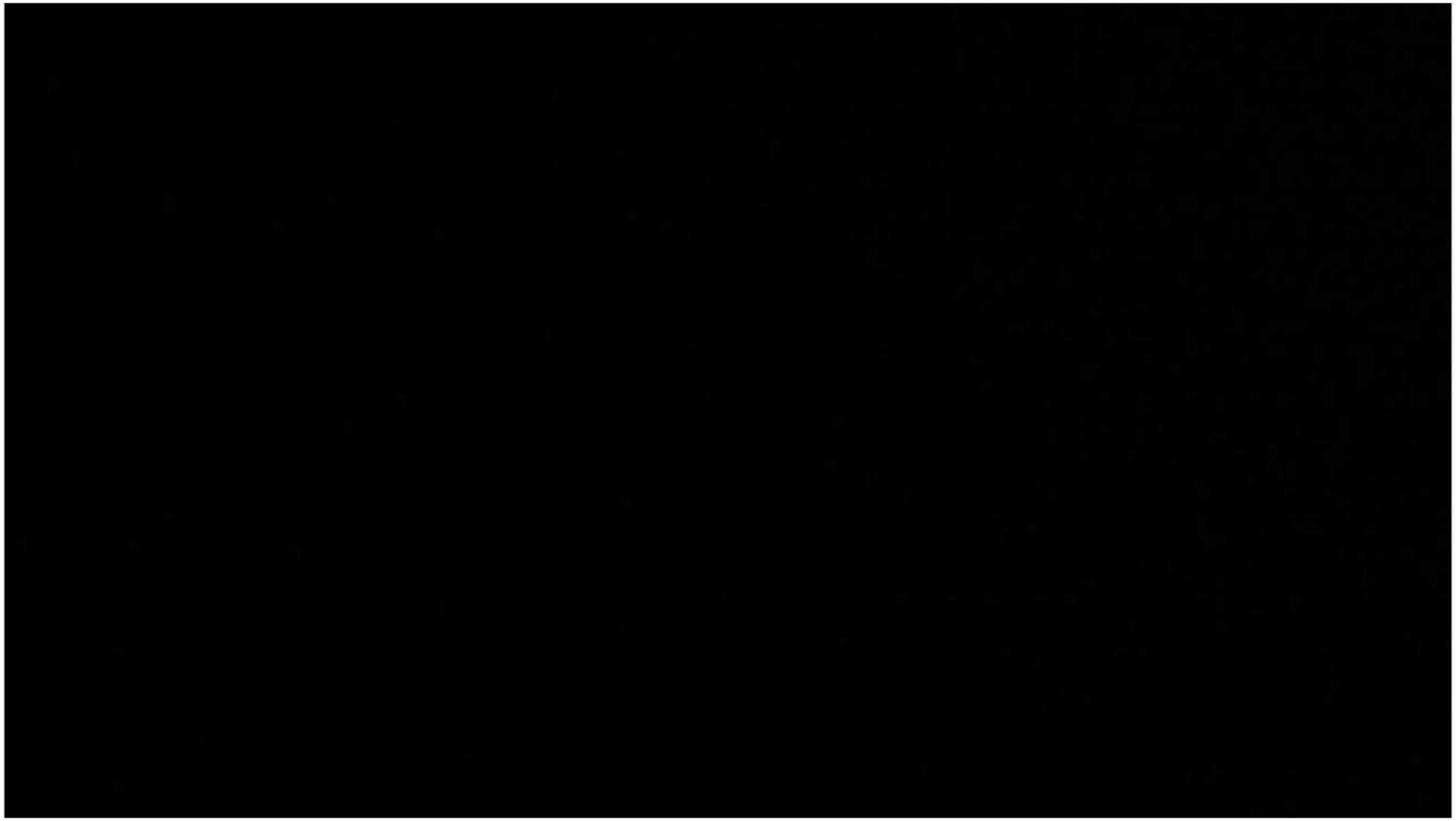
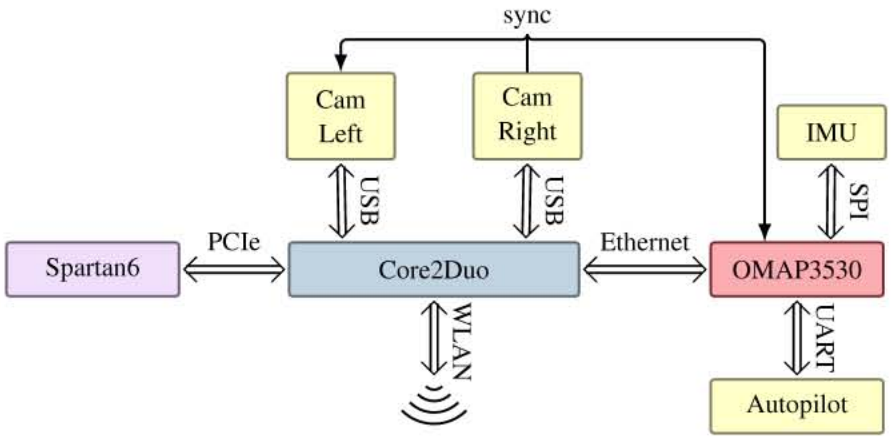
in collaboration with

DLR Oberpfaffenhofen

Example of Collaborative Exploration from DLR

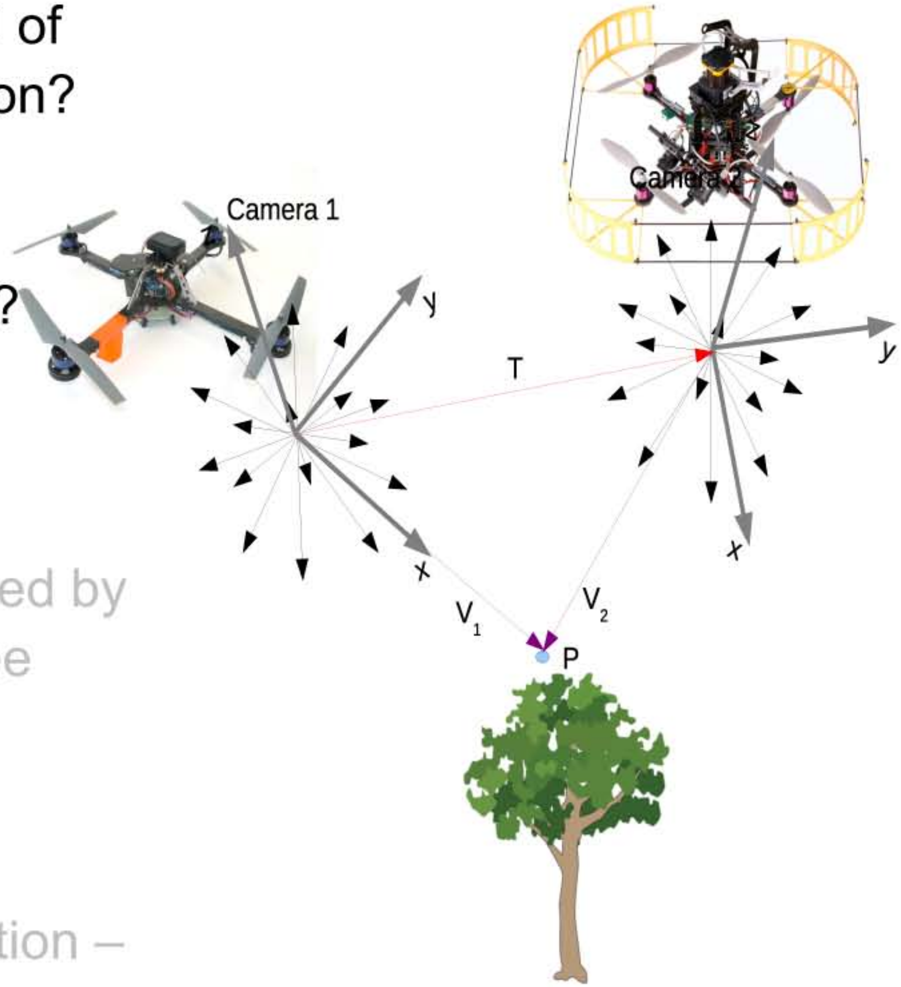


System architecture (hardware)

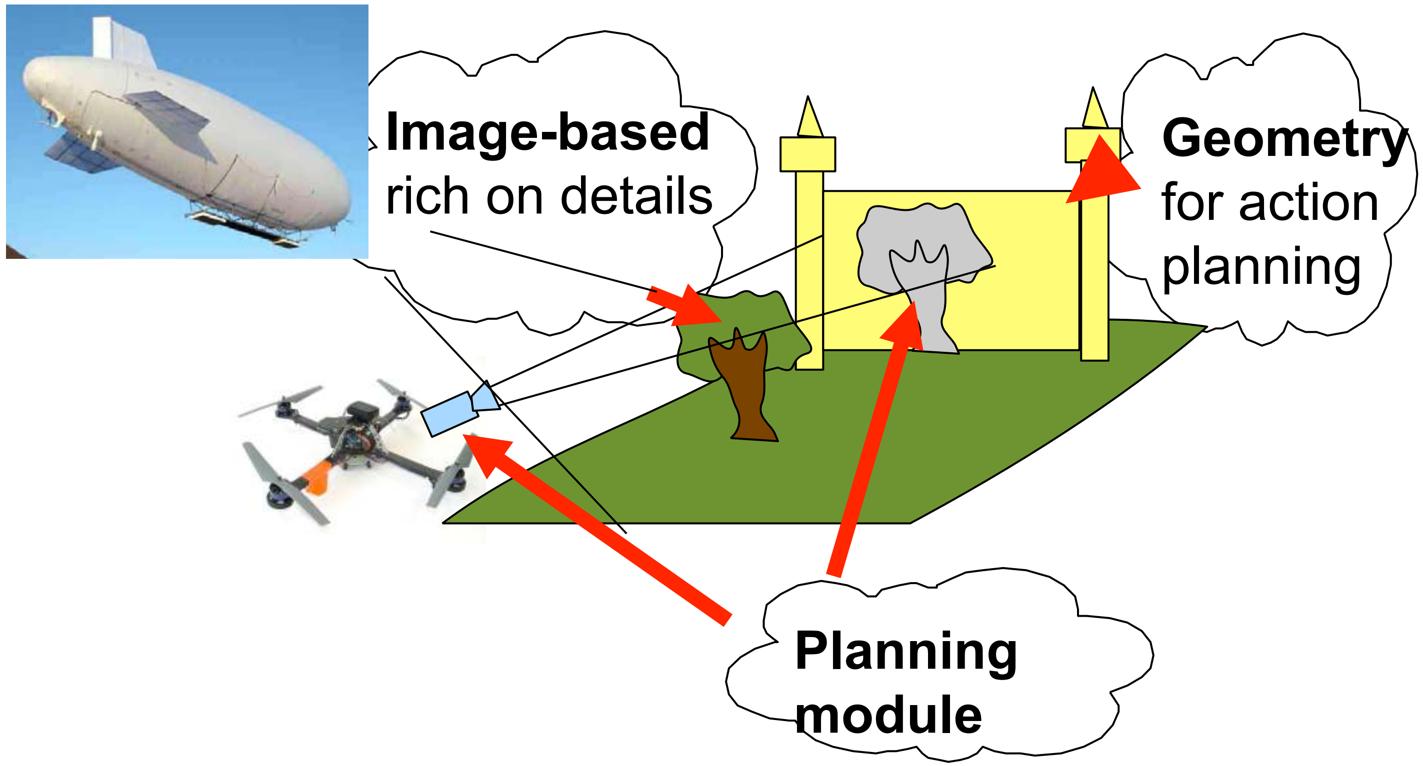


Aspects of Collaborative Swarm Perception

- What is the appropriate level of detail for model representation?
- How to boost measurement sensitivity at large distances?
- Global vs. local perception?
- Increase the exploration speed by sharing the exploration of free space
- Completeness of the instantaneous scene perception – true 3D instead of 2.5D



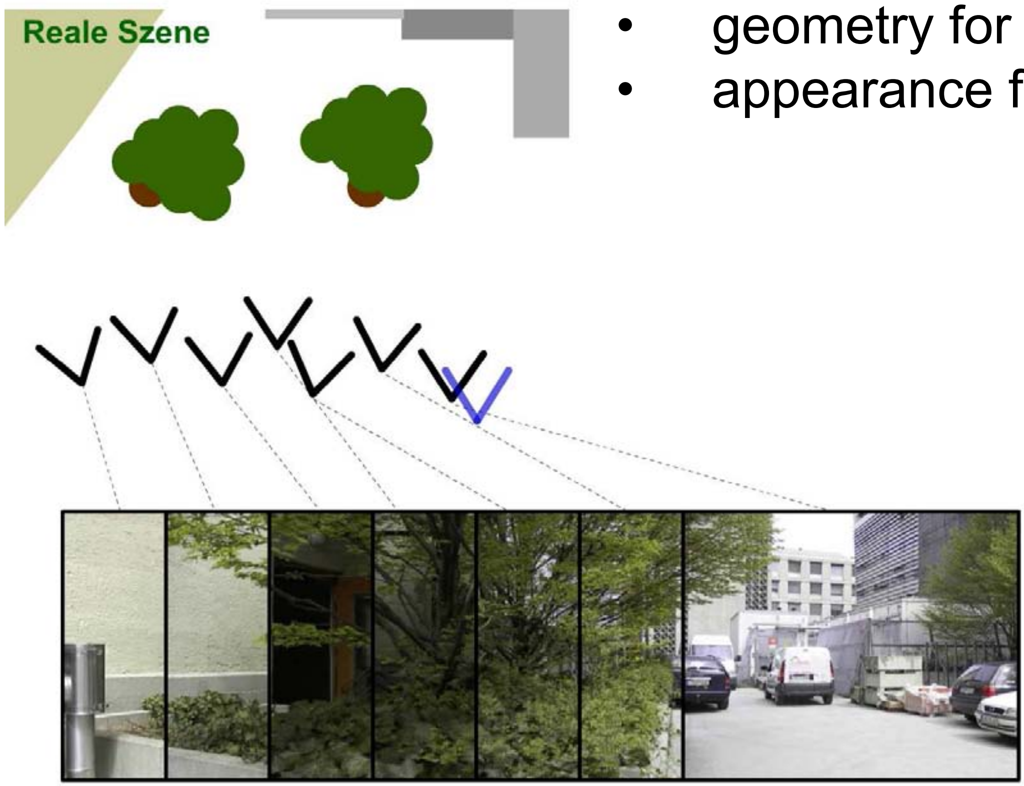
Level of Detail in Modelling



- Joint geometry and image based environment modelling

Constraints on the Level of Detail

(work with E.Steinbach, TUM)

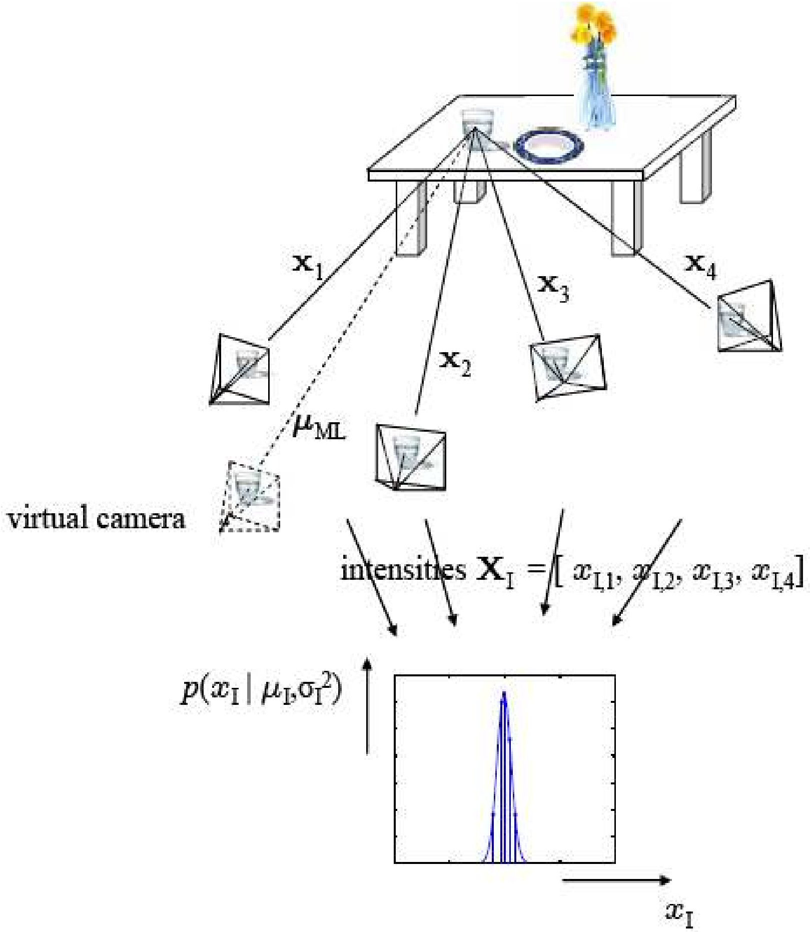


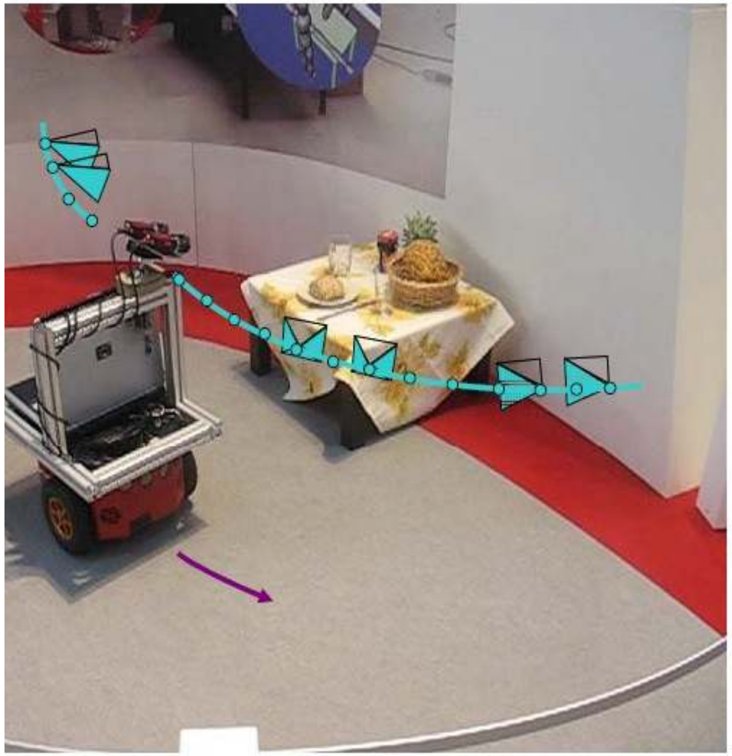
Hybrid Model for world representation

- geometry for collision avoidance
- appearance for view prediction

W. Maier, E. Mair, D. Burschka, and E. Steinbach. ICRA 2009.

Reconstruction of a hybrid (appearance/geometry) model





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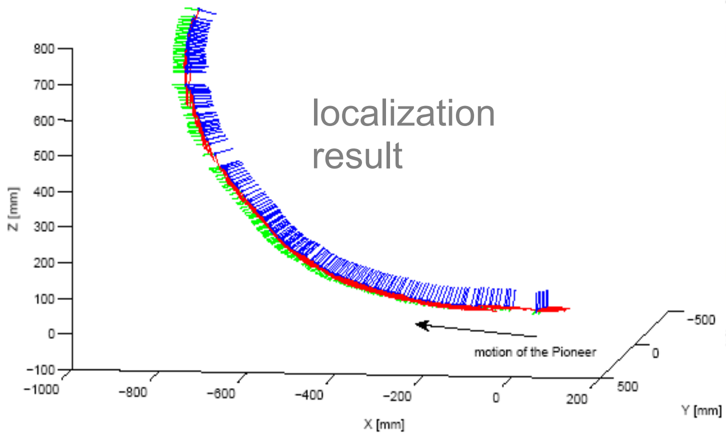
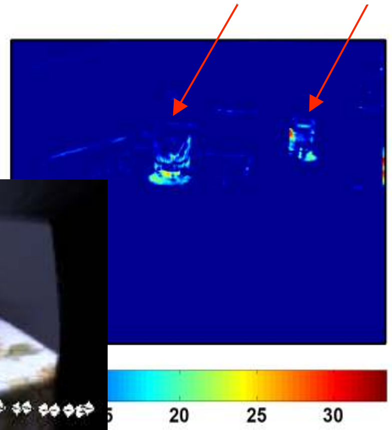
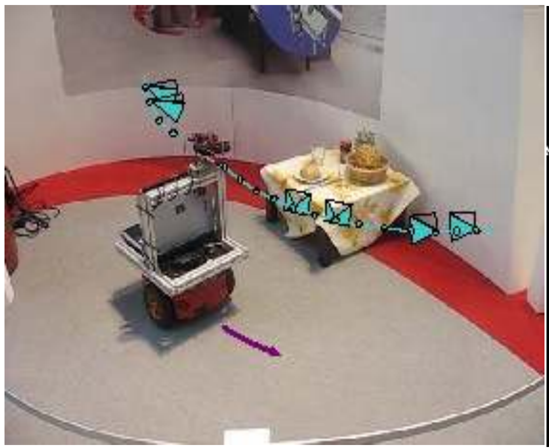
Visual Localization for Visual Environment Modeling





surprise
trigger

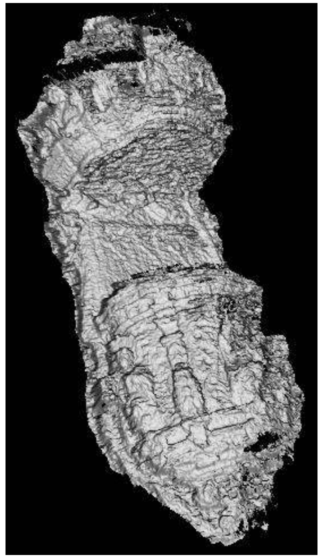


Modeling from Images (collaboration with M. Jagersand UAlberta)

Processing (SFM or SFS)

Cameras

- +Inexpensive, easy to use
- +Textures automatically registered with SFM geometry
- +Easy to get multiple viewpoints
- +Redundant data
- -Global metric accuracy of SFM geometry not always good
- -Needs image features (texture) to compute 3D geometry



Geometry from images

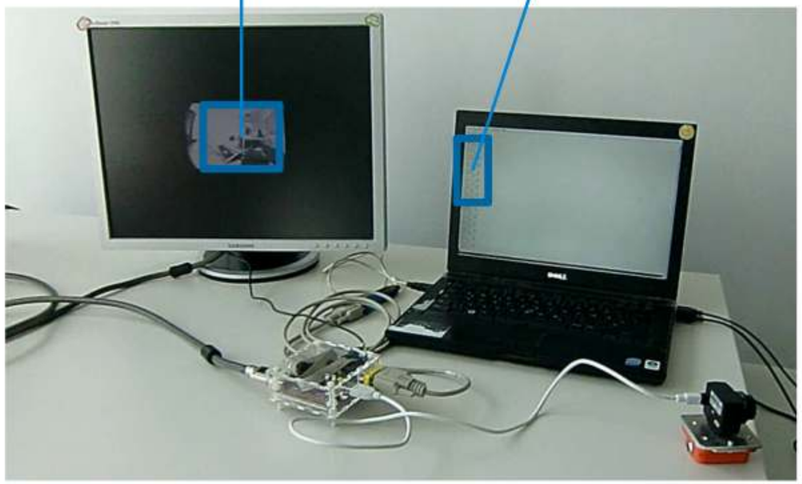
Combining the geometry and image-based approaches

- Can add realism from image-based rendering
- Can fill-in with SFM geometry where laser is occluded, or more fine detail is needed.
- Cumbersome registration of models: SFM model may re-project well, but still not have a high Euclidean accuracy

Local Feature Tracking Algorithms

- Image-gradient based → Extended KLT (ExtKLT)
  - patch-based implementation
  - feature propagation
  - corner-binding
  - \+ sub-pixel accuracy
  - algorithm scales bad with number of features

- Tracking-By-Matching → AGAST tracker
  - AGAST corner detector
  - efficient descriptor
  - high frame-rates (hundrets of features in a few milliseconds)
  - \+ algorithm scales well with number of features
  - pixel-accuracy



Mair, Hager, Burschka, Suppa, Hirzinger
ECCV, Springer, 2010

Adaptive and Generic Accelerated Segment Test (AGAST)

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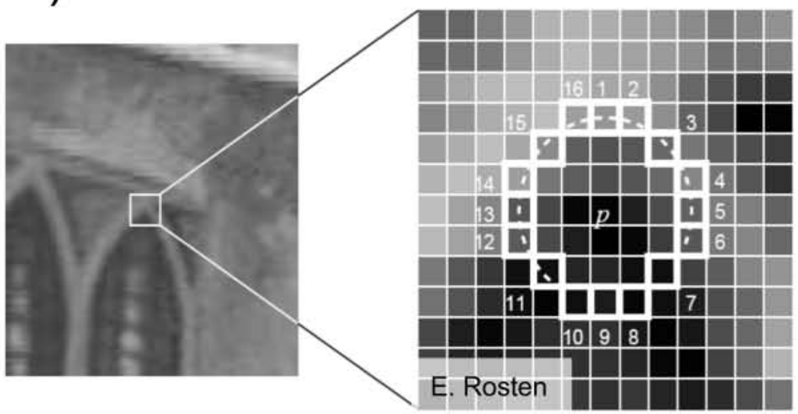
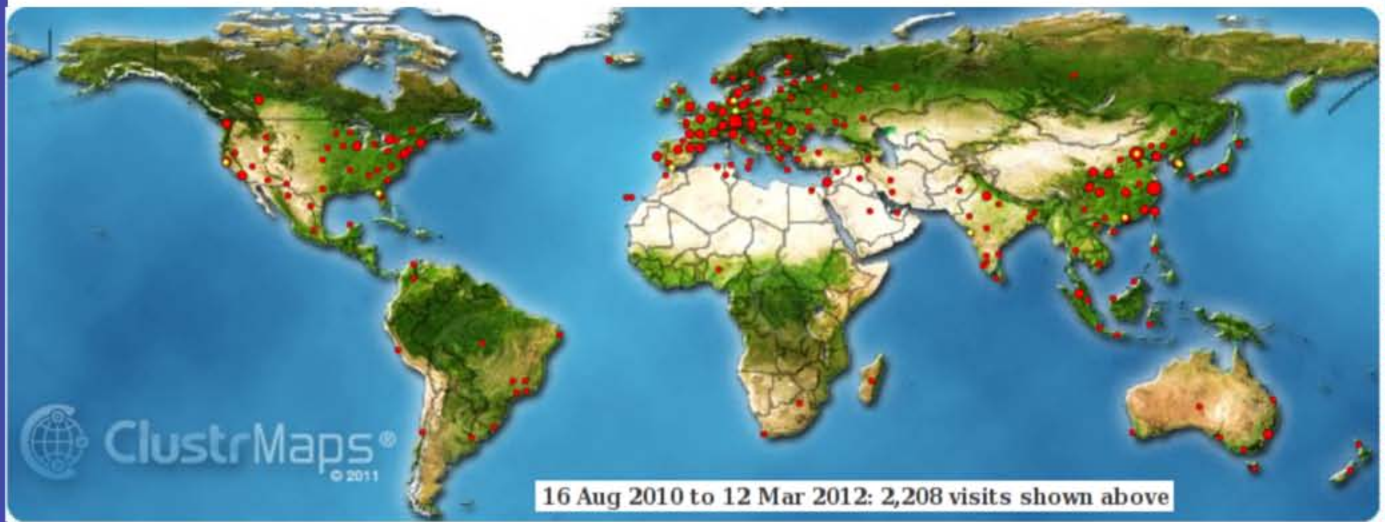
- Improvements compared to FAST:
- full exploration of the configuration space by backward-induction (no learning)
- binary decision tree (not ternary)
- computation of the actual probability and processing costs (no greedy algorithm)
- automatic scene adaption by tree switching (at no cost)
- various corner pattern sizes (not just one)



<u>No drawbacks!</u>

AGAST – Open Source Software

- •AGAST, AGASTPP @ Sourceforge
  - > 5000 downloads
- •AGAST in OpenCV
- •AGAST used by BRISK



Current Country Totals
From 16 Aug 2010 to 12 Mar 2012

China (CN)	489
Germany (DE)	382
United States (US)	217
France (FR)	134
Korea, Republic of (KR)	95
Japan (JP)	89
Spain (ES)	71
Switzerland (CH)	67
United Kingdom (GB)	57
Italy (IT)	47
India (IN)	43
Taiwan (TW)	42
Australia (AU)	39
Canada (CA)	39
Malaysia (MY)	33
Netherlands (NL)	30
Russian Federation (RU)	26
Brazil (BR)	25
Poland (PL)	21
Austria (AT)	19
Romania (RO)	18
Europe (EU)	17
Denmark (DK)	13
Sweden (SE)	13
Greece (GR)	11
Portugal (PT)	11
Turkey (TR)	11
Hong Kong (HK)	10
Israel (IL)	8
Belgium (BE)	8
Chile (CL)	8
Vietnam (VN)	8
Singapore (SG)	7
New Zealand (NZ)	6
Indonesia (ID)	6
Iran, Islamic Republic of (IR)	6
Thailand (TH)	6
Mexico (MX)	6

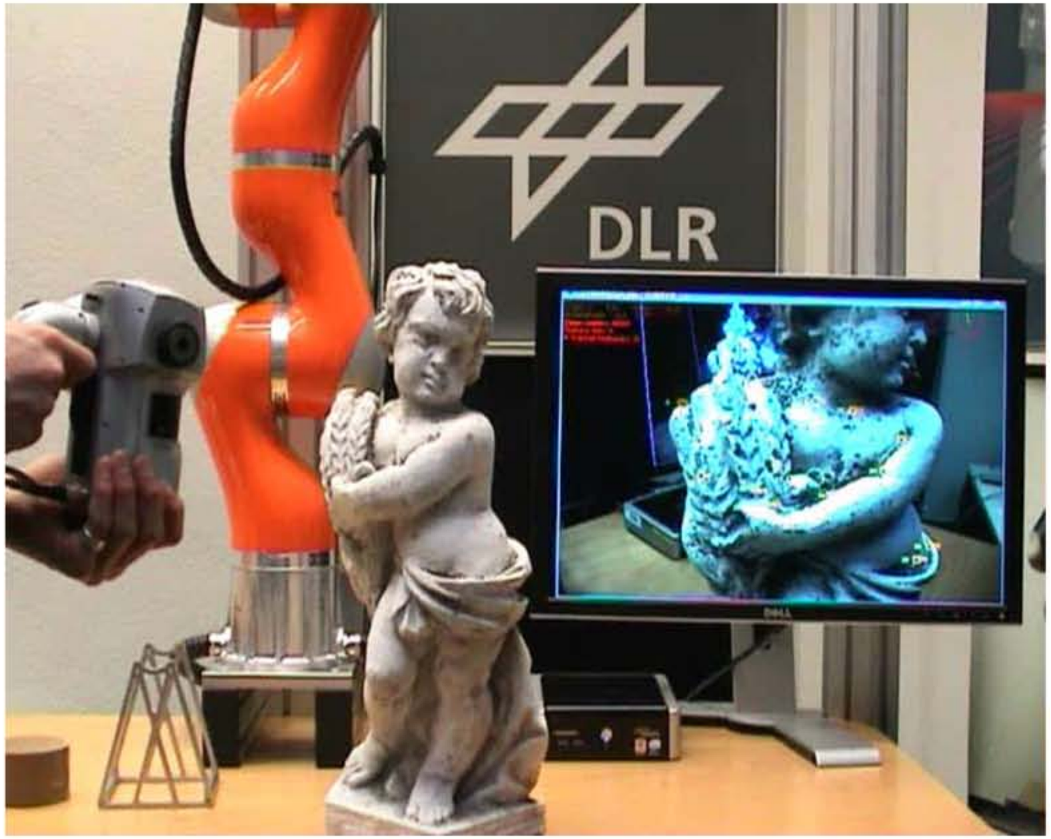
Feature Propagation

no feature propagation

Strobl, Mair, Bodenmüller, Kielhofer, Sepp, Suppa, Burschka, Hirzinger
IROS, IEEE/RSJ, 2009, Best Paper Finalist

Mair, Strobl, Bodenmüller, Suppa, Burschka
KI, Springer Journal, 2010

- Two motion prediction concepts
  - 2D feature propagation by motion derivatives
  - IMU-based feature prediction
- Combination of both:
  - translation propagation by feature velocity (2D)
  - rotation propagation by gyroscopes



Feature Propagation

linear feature propagation

Strobl, Mair, Bodenmüller, Kielhofer, Sepp, Suppa, Burschka, Hirzinger
IROS, IEEE/RSJ, 2009, Best Paper Finalist
Mair, Strobl, Bodenmüller, Suppa, Burschka
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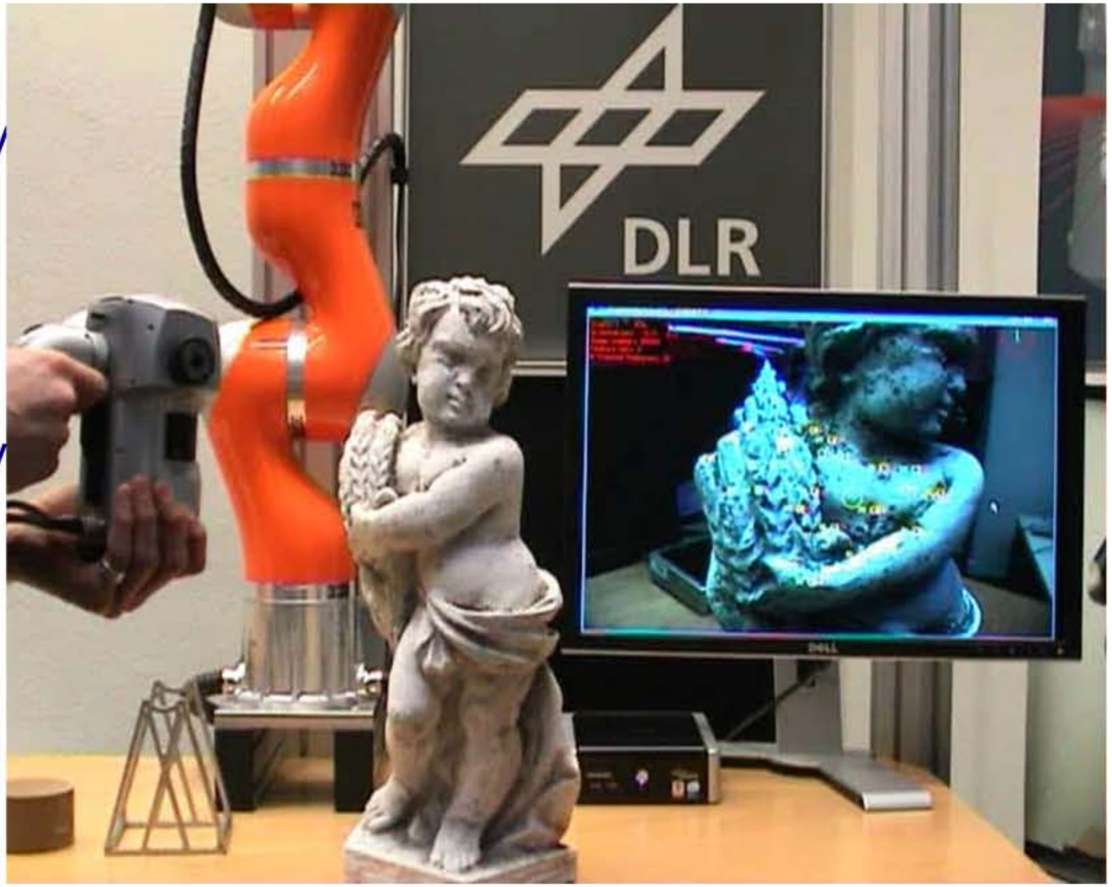

Feature Propagation
linear + gyros based prop.

Strobl, Mair, Bodenmüller, Kielhofer, Sepp, Suppa, Burschka, Hirzinger
IROS, IEEE/RSJ, 2009, Best Paper Finalist
Mair, Strobl, Bodenmüller, Suppa, Burschka
KI, Springer Journal, 2010

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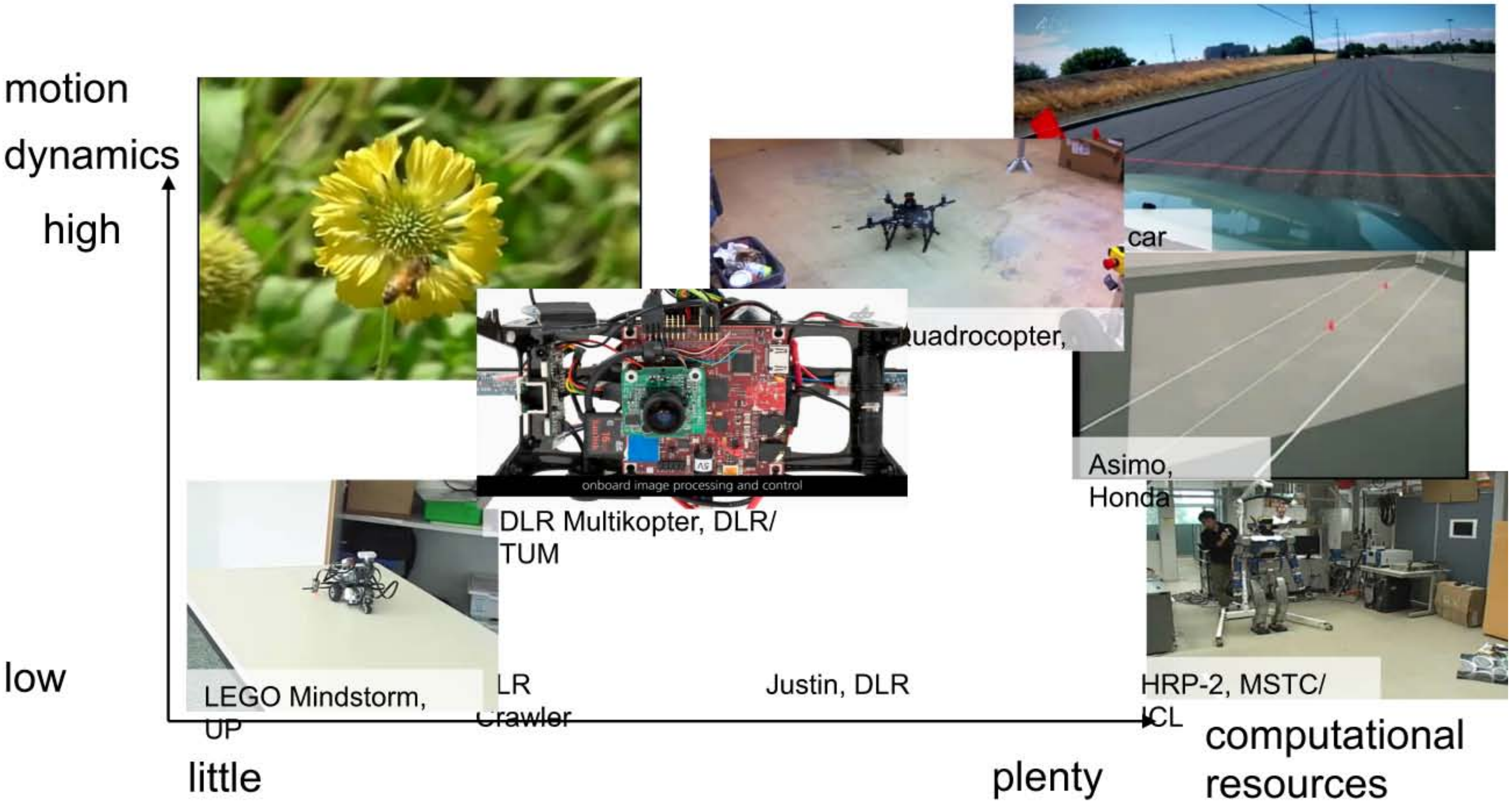
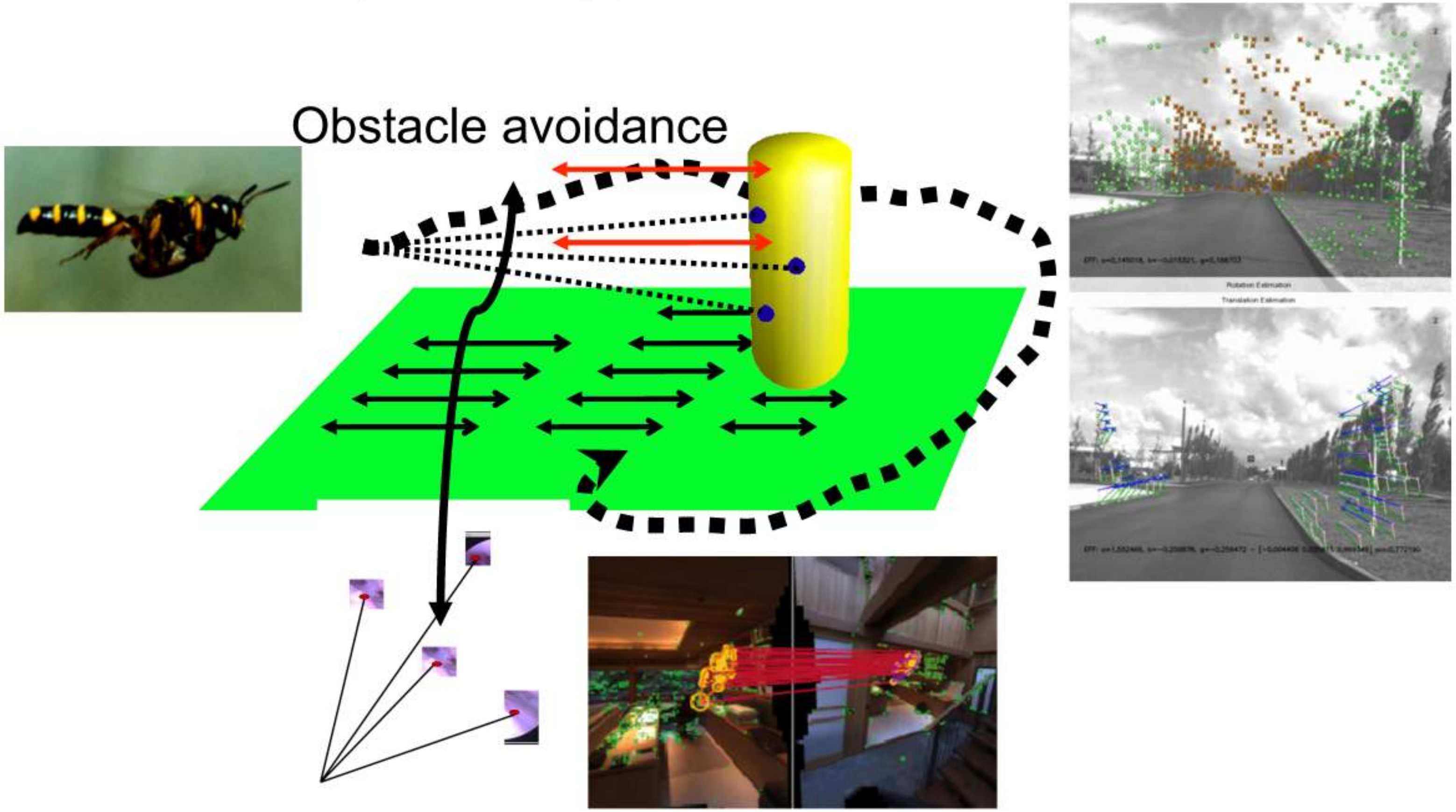
Mobile Robot Navigation



Z_∞ – Algorithm at Work

Mair, Burschka
Mobile Robots Navigation, book chapter, In-Tech, 2010

Simple sensors, low processing power



„Simple“ Image Acquisition

60 images taken with a standard low cost digital camera

Z_∞-Testrun

Framerate: 30 Hz

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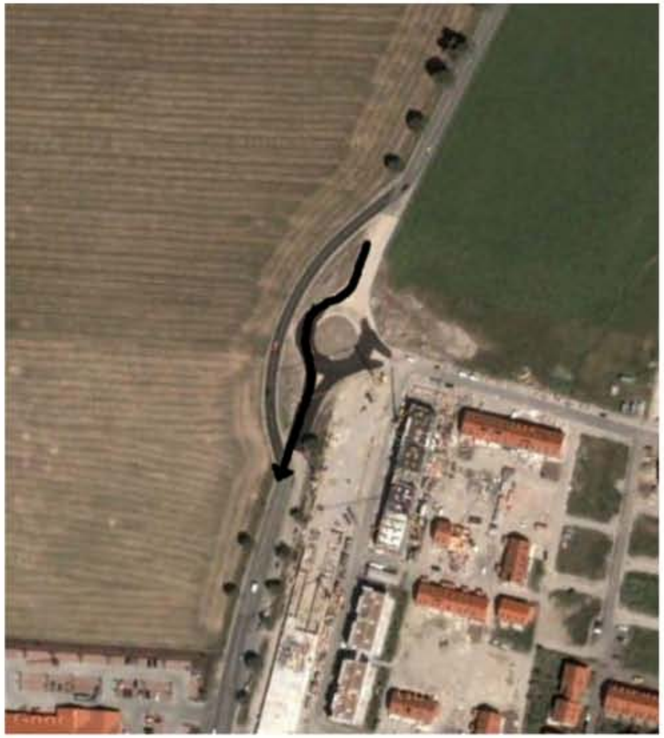
Navigation results

Burschka,Mair RobotVision 2008



Estimation of the 6 Degrees of Freedom

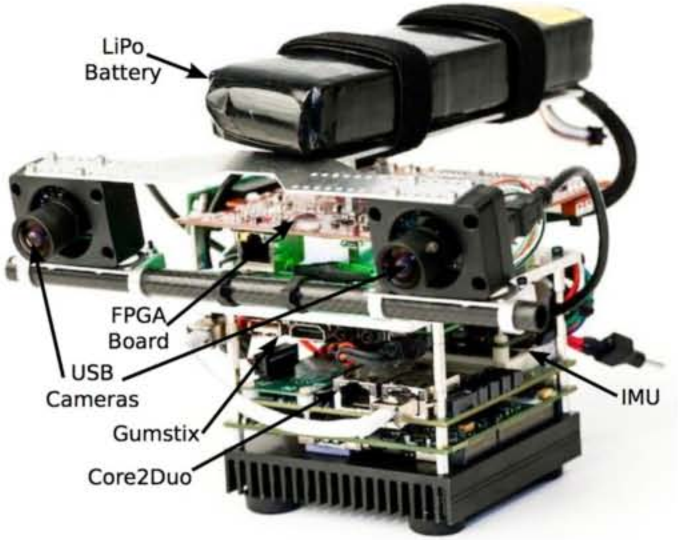
Estimation of 3 rotational angles

Estimation of a translation vector

3D Reconstruction from the Images
(with H.Hirschmüller)

Mobile stereo perception device

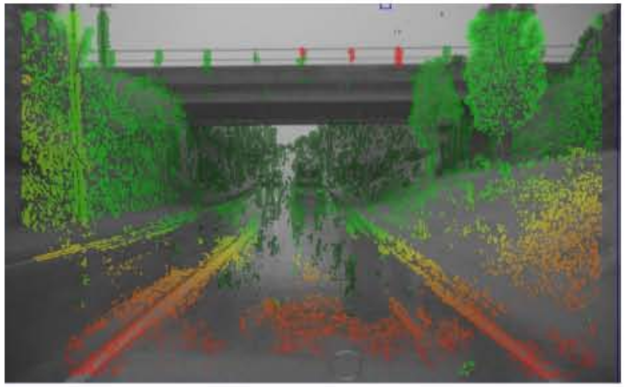
Live demonstration RSS 2012



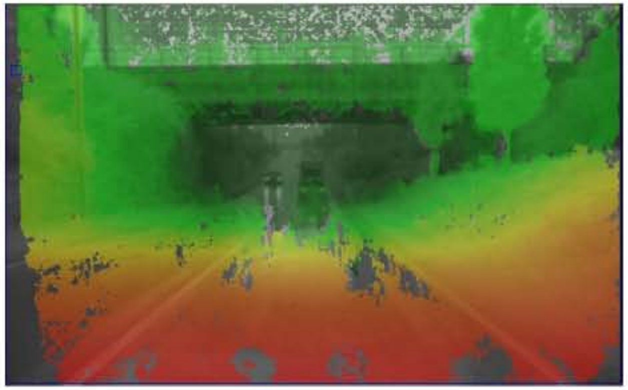
- Key frame based visual odometry
- SGM stereo on FPGA
- Inertial/Odometry fusion with measurements delay compensation

Depth image calculation on FPGA

- Semi Global Matching (SGM) [Hirschmüller2008]
- FPGA implementation: [Gehrig et al., 2009]
  - acceleration by parallelization
  - acceleration by pipelining
  - 0.5 MPixel depth images at 14.6 Hz
  - 250 ms latency



Correlation based Stereo



Semi-global matching

Images are a courtesy of Stefan Gehrig, Daimler AG

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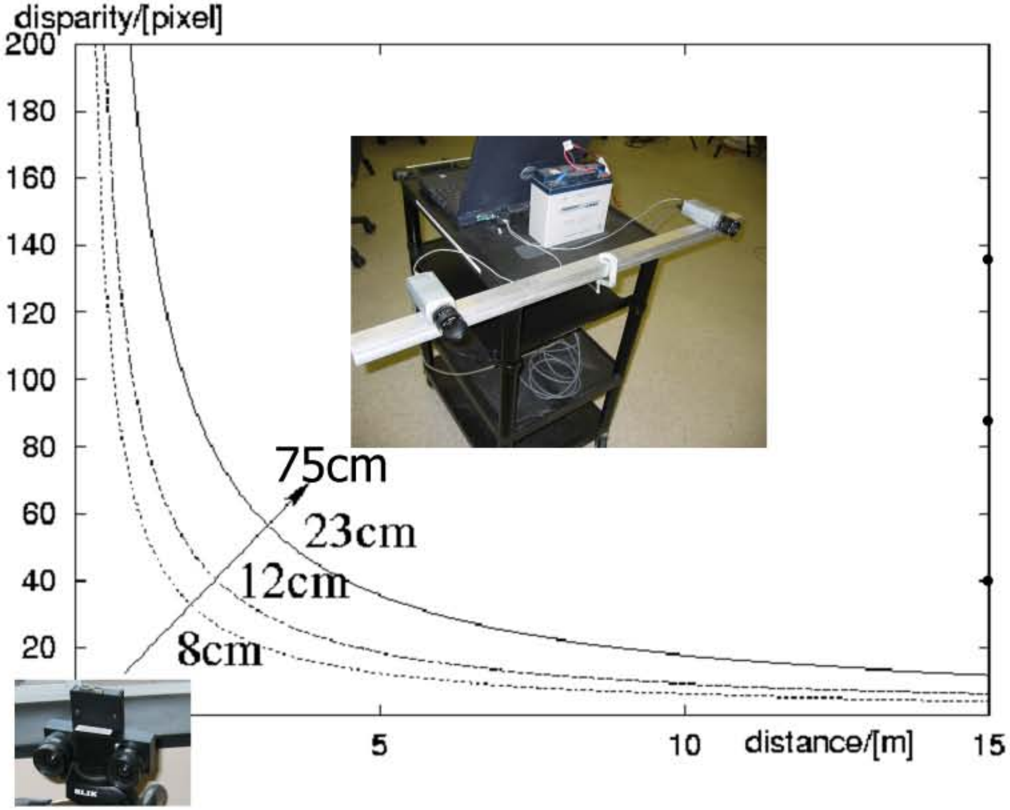
Swarms to boost resolution



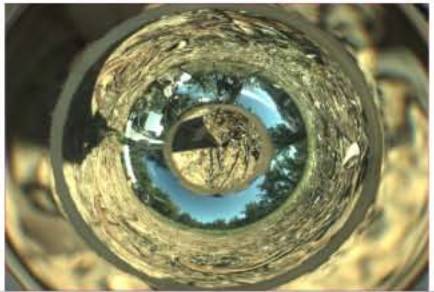
$$d_p = \frac{B \cdot f}{p_x} \cdot \frac{1}{z} [pixel]$$

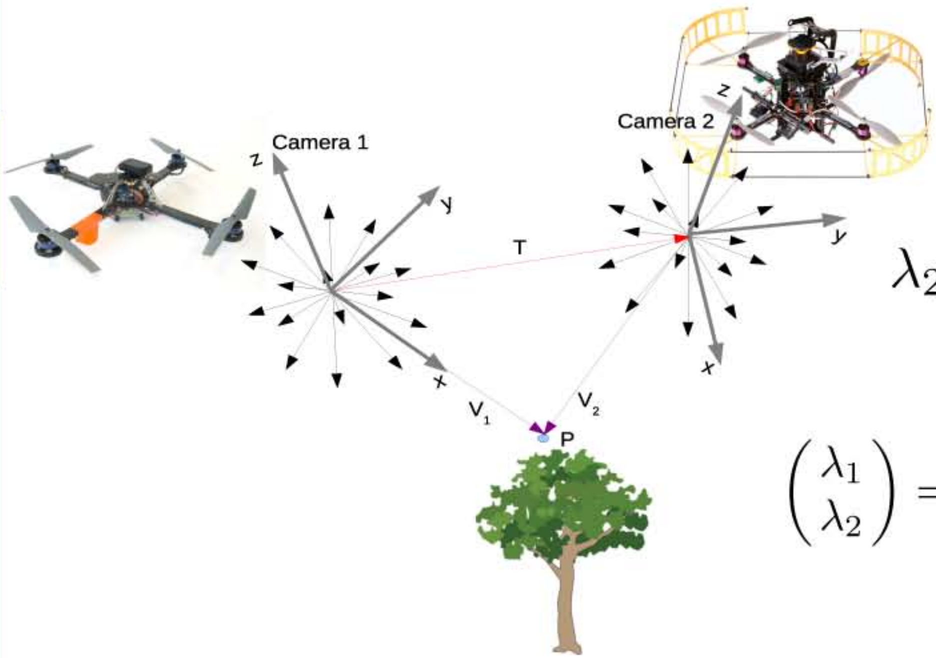
Possible measures:

- Increase of the distance between cameras (B)
- Increase of the focal length (f) → field of view
- Decrease of the pixel-size (p_x) → resolution of the camera

Collaborative Reconstruction with Self-Localization

(CVPR Workshop on Vision in Action: Efficient strategies for cognitive agents in complex environments, Marseille : France (2008))





$$V_2 = \mathbf{R} * (V_1 + T)$$

$$\lambda_2 n_2 = \mathbf{R} * (\lambda_1 n_1 + T).$$

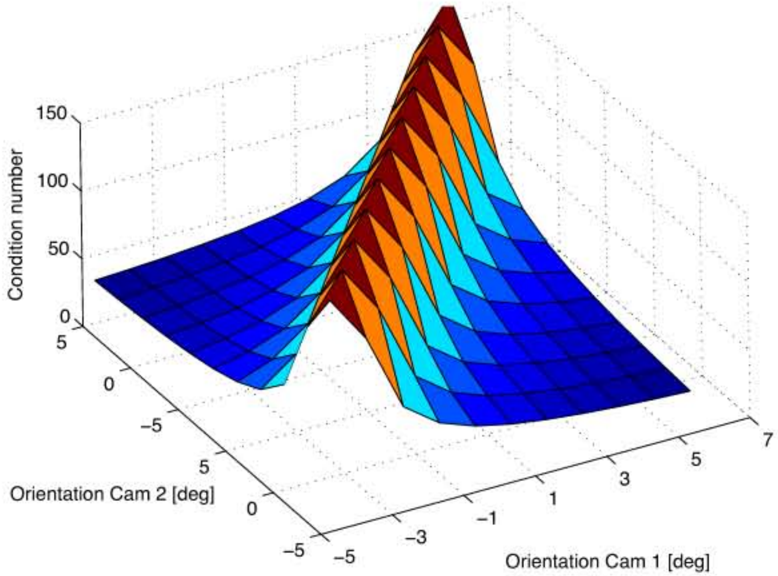
$$(-\mathbf{R}n_1,\, n_2) \begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix} = \mathbf{R} \cdot T$$

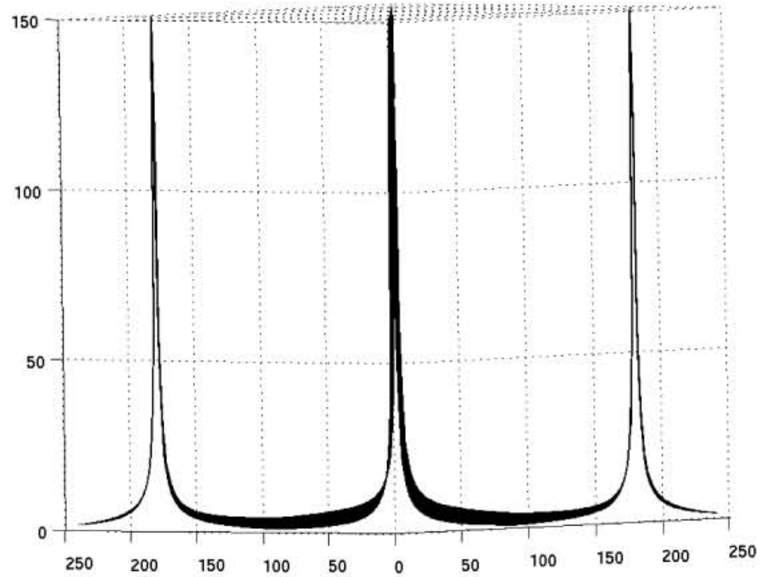
$$\begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix} = (-\mathbf{R}n_1,\, n_2)^{-*} \cdot \mathbf{R} \cdot T = \mathbf{D}^{-*} \cdot \mathbf{R} \cdot T$$

$$\mathbf{D}^{-*} = (\mathbf{D}^{\mathbf{T}} \cdot \mathbf{D})^{-1} \cdot \mathbf{D}^{\mathbf{T}}.$$

Condition number for an angular configuration

$$(\mathbf{D}^{-*} + \epsilon\delta\mathbf{D}^{-*})\boldsymbol{T_b} = \lambda + \epsilon\delta\lambda$$

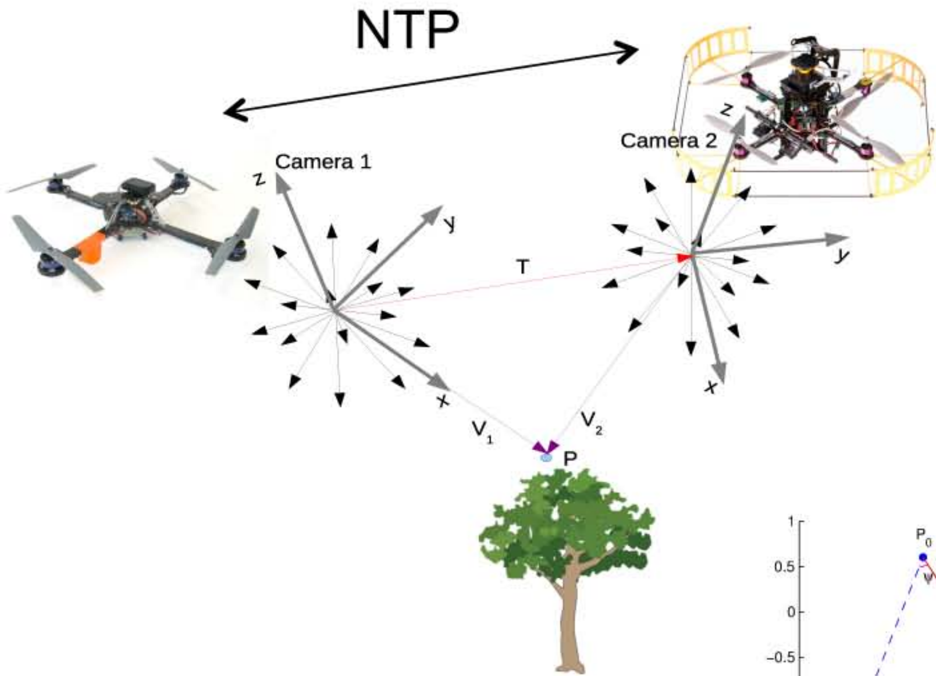


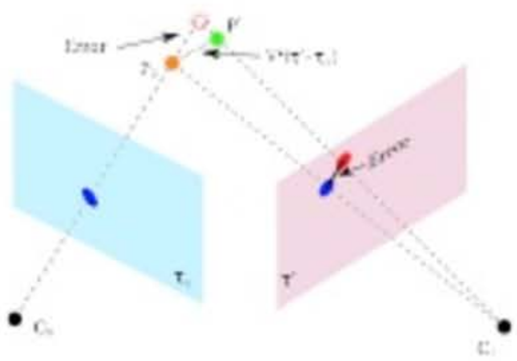


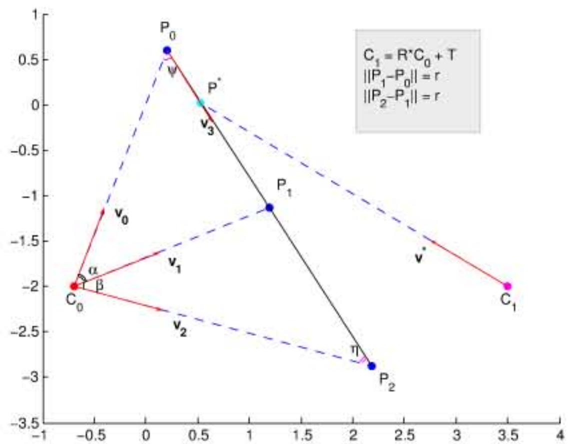
Best observation by 90° viewing angle

Submitted VISAPP 2014

Asynchronous stereo for dynamic scenes



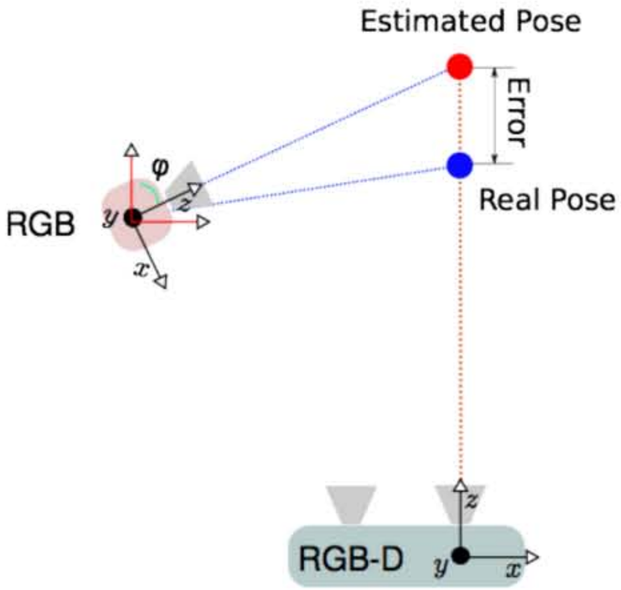


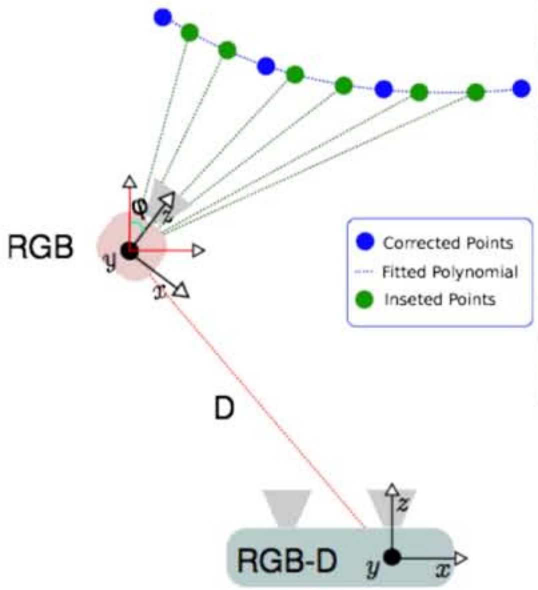


Enhancement of Stereo Data

IROS 2013

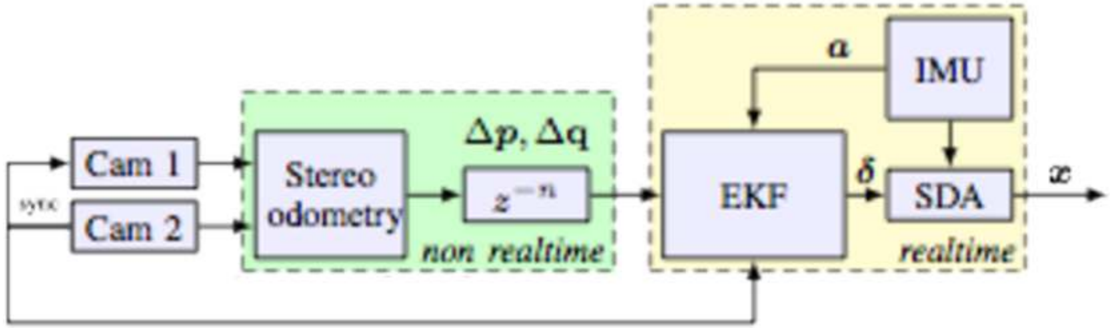
Multimodal Sensor Fusion





INS filter design

[Schmid et al. IROS 2012]



- Synchronization of realtime and non realtime modules by sensor hardware trigger

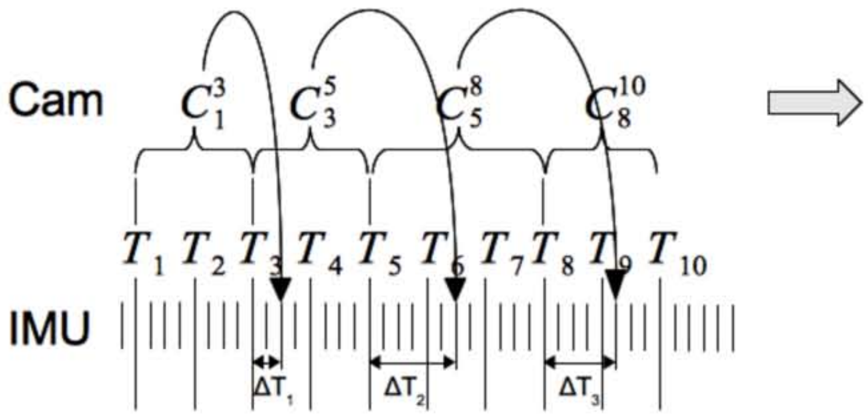
- Direct system state: $x = (p_{ob}^{o,T} \quad v_{ob}^{n,T} \quad q_b^{o,T} \quad b_a^{b,T} \quad b_\omega^{b,T})^T$
- High rate calculation by „Strap Down Algorithm“ (SDA)

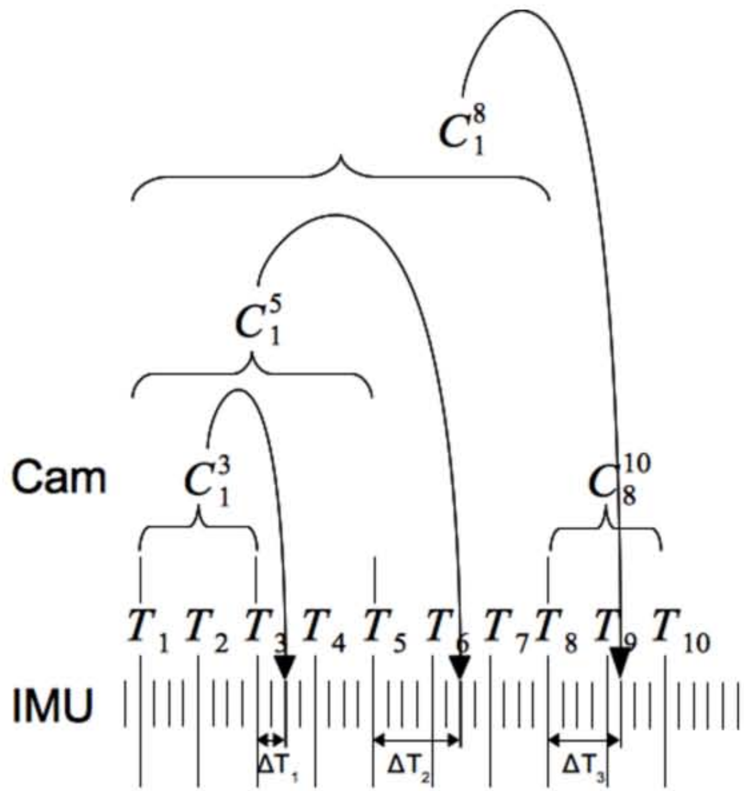
- Indirect system state: $\delta = \left(\delta_p^{o,T} \quad \delta_v^{o,T} \quad \delta_\psi^{o,T} \quad \delta_{b_a}^{b,T} \quad \delta_{b_\omega}^{b,T}\right)^T$
- Estimation by indirect Extended Kalman Filter (EKF)

- Measurements: „pseudo gravity“, key frame based stereo odometry
- Measurement delay compensation by filter state augmentation

Key frame based stereo odometry

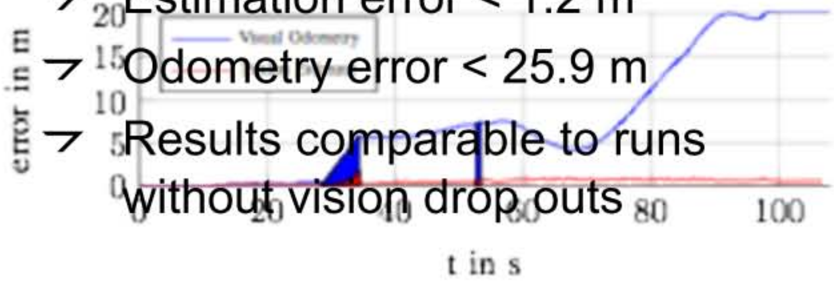
- Delta measurements referencing key frames
- Locally drift free system state estimation





Exploration with an MAV (DLR)

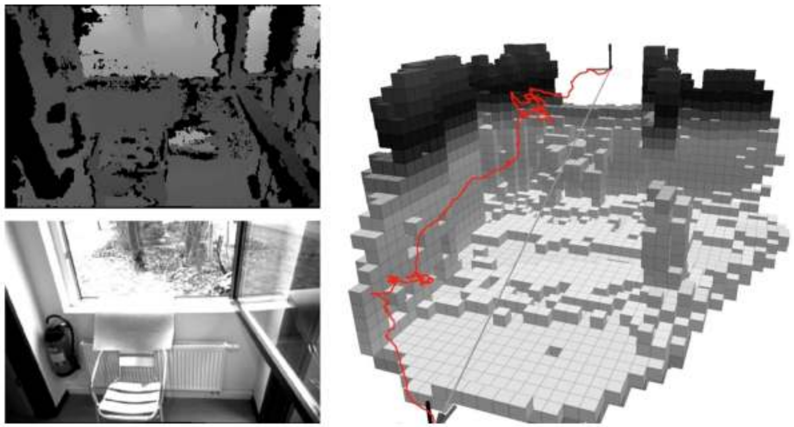
- 70 m trajectory
- Ground truth by tachymeter
- 5 s forced vision drop out with translational motion
- 1 s forced vision drop ou[redacted] with rotational motion

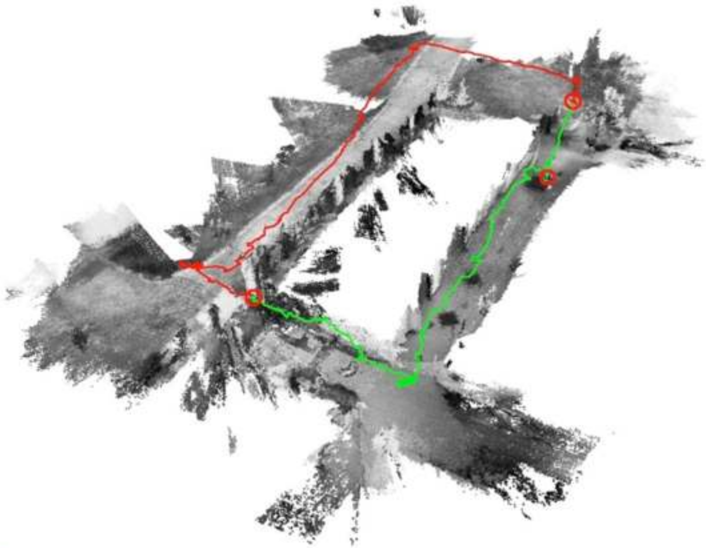


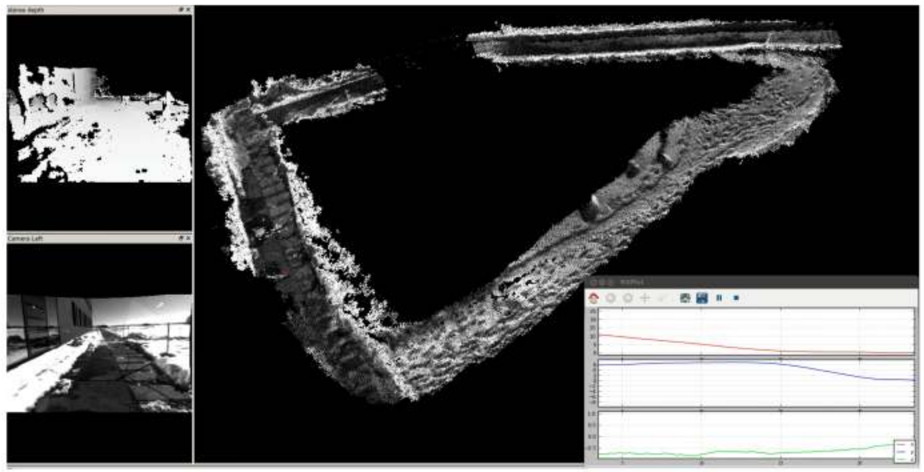
- Estimation error < 1.2 m
- Odometry error < 25.9 m
- Results comparable to runs without vision drop outs

Mixed indoor/outdoor exploration

- Autonomous indoor/outdoor flight of 60m
- Mapping resolution: 0.1m
- Leaving through a window
- Returning through door

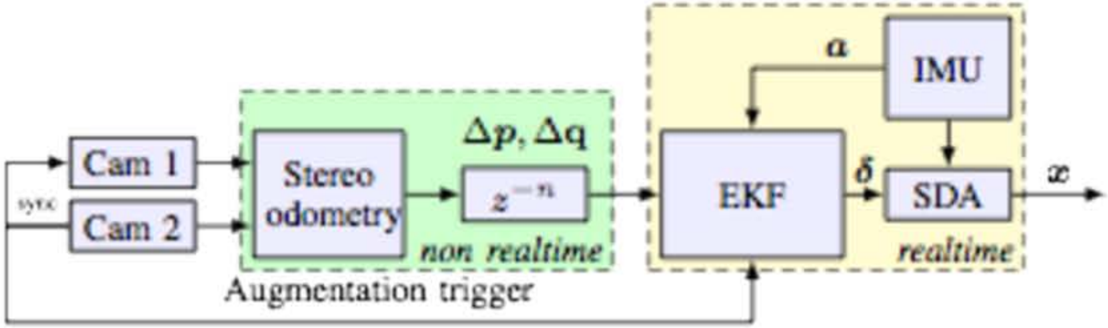






INS filter design (DLR)

[Schmid et al. IROS 2012]



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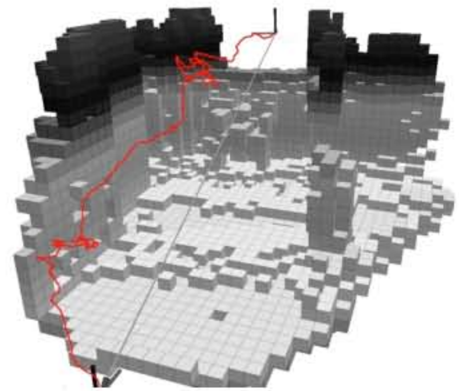

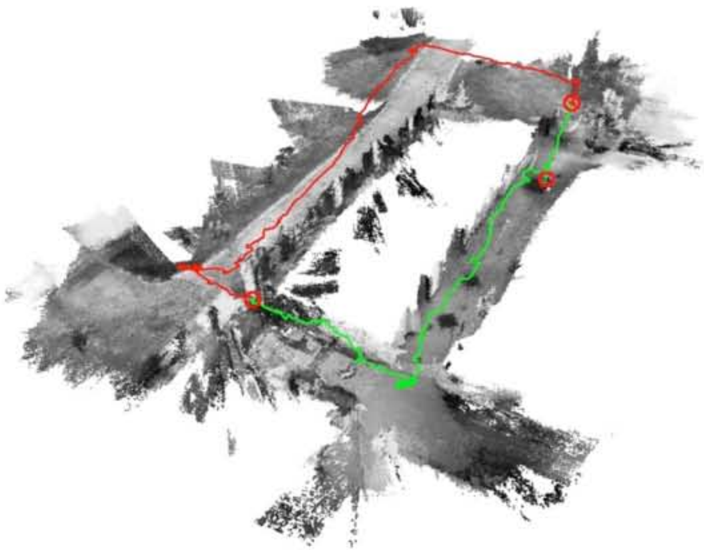

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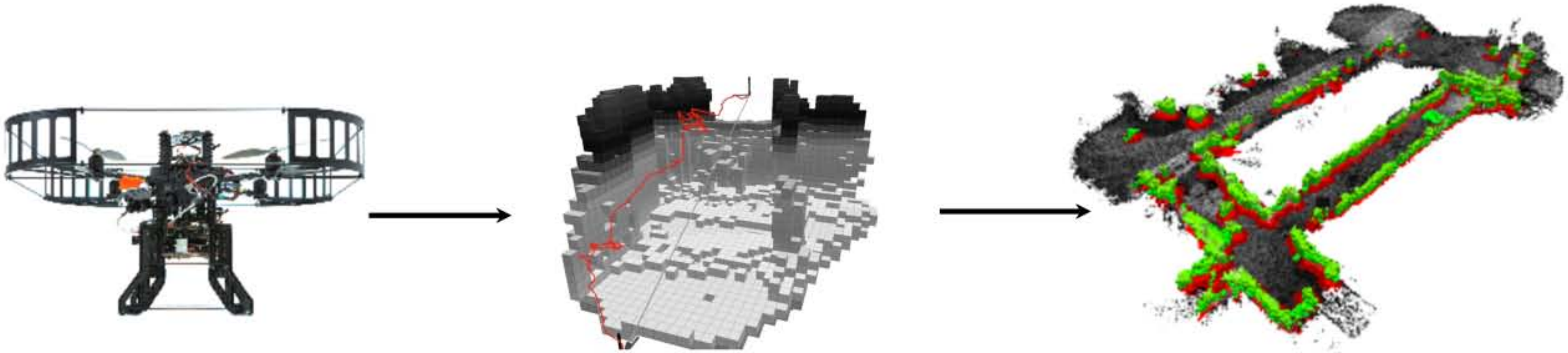
Conclusion

- Multicopters for SAR and disaster management scenarios
- Swarms for better resolution
- Modelling complexity needs to be adapted to the task
- Synchronisation necessary



Towards Autonomous MAV Exploration in Cluttered Indoor and Outdoor Environments >