# Computer Vision for Mobile Robot Navigation

Heiko Hirschmüller[12], Korbinian Schmid[12], Michael Suppa[2]

[1]Institute of Robotics and Mechatronics
German Aerospace Center (DLR)
Oberpfaffenhofen

[2]Roboception GmbH
Munich

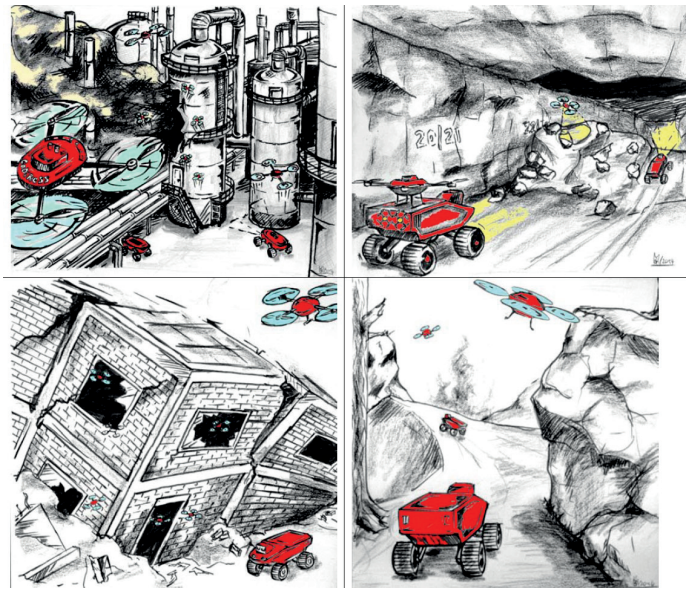

DLR



# Challenges in Mobile Robot Navigation

Planetary Exploration

Search and Rescue



➔ Common in both scenarios:
Autonomous navigation in unknown, unstructured, uneven terrain

DLR

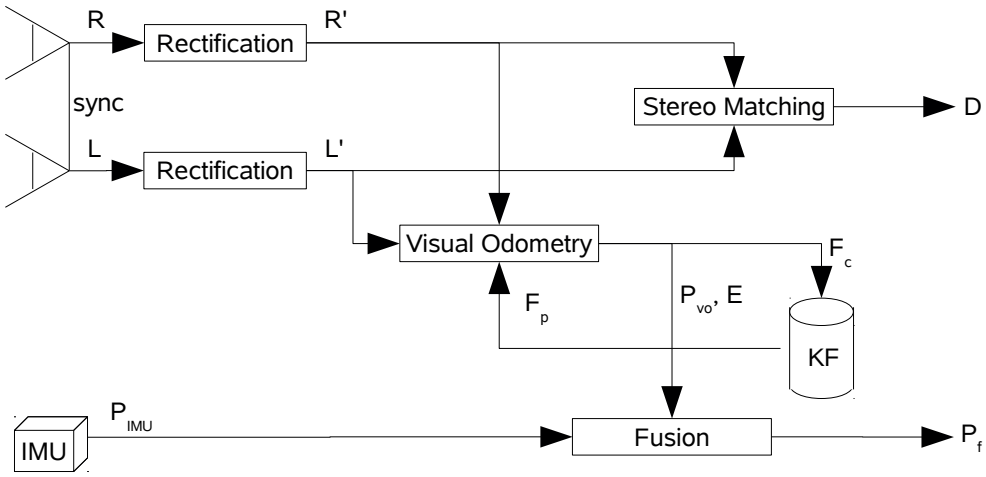
# Stereocamera as Main Sensor

- Passive stereo matching is well suited for textured environments
- Outdoor scenes/natural environments are typically well textured
- Many other sensors fail due to sunlight
- Cameras are small, lightweight and robust
- Images contain more information than just depth
- Space proven by
  - NASA Mars Exploration Rover (Spirit and Opportunity)
  - NASA Mars Science Laboratory (Curiosity)





# Vision Pipeline




L: Left image
R: Right image
D: Disparity image
$F_c$: Current features
$F_p$: Previous features
$P_{vo}$: Visual odo. pose
$P_{IMU}$: IMU pose
$P_f$: Fused pose

# Dense Stereomatching

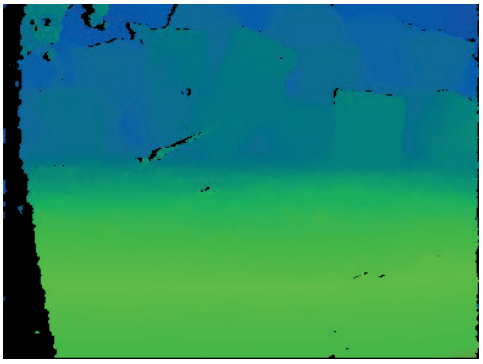
- Semi-Global Matching
  (Hirschmüller, CVPR 2005 & TPAMI 2008)

- Awards:
  - DLR Wissenschaftspreis 2009
  - Carl-Pulfrich-Award at PhoWo 2011

- Offers higher spatial resolution and has less problems with poor texture as correlation

- Implemented on Spartan 6 FPGA board, i.e. Daimler solution for driver assistance
  (Gehrig et al., 2008; www.6d-vision.com)

- 14.6 Hz with 1024 x 508 pixel image size and 128 disparity steps



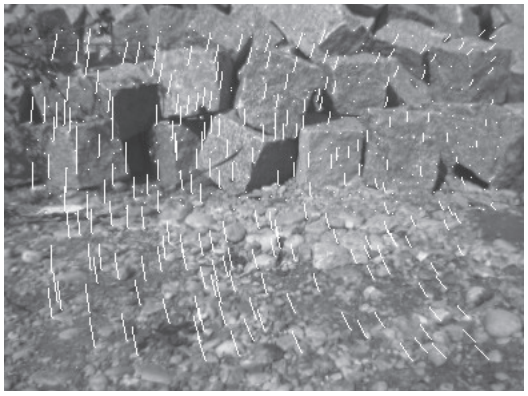




# Robust Ego Motion Estimation

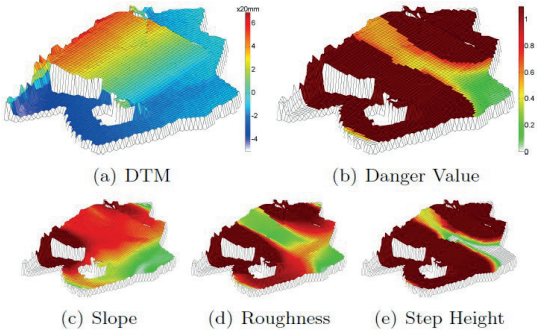
- Visual Odometry
  - Tracking of natural features
  - Computation of frame to frame ego motion with 6 DoF
  - Very accurate
  - Scene and illumination dependent
  - Hirschmüller et al. (ICARCV 2002)

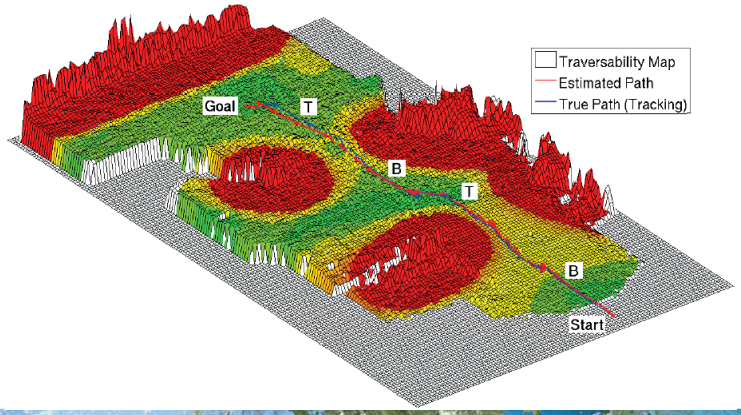
- Fusion of visual odometry with IMU data
  - Increases robustness
  - Compensates latency of vision
  - Enables real-time control of robot
  - Schmid et al. (JFR 2014)



# Mapping and Path Planning

- Incremental fusion of disparity images into 2.5D height model
- Traversability estimation, depending on
  - Roughness
  - Steepness
  - Obstacles
- Path planning
- Chilian und Hirschmüller (IROS 2009)
- Stelzer, Hirschmüller und Görner (IJRR 2012)



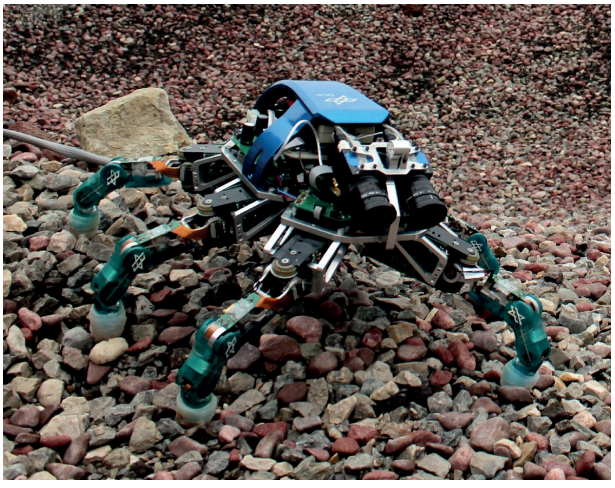





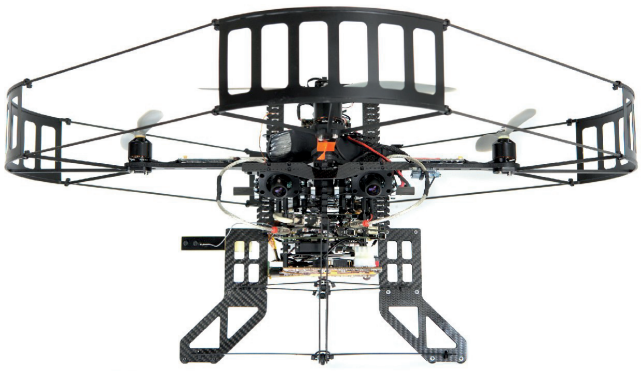



# Search and Rescue Applications

DLR Crawler

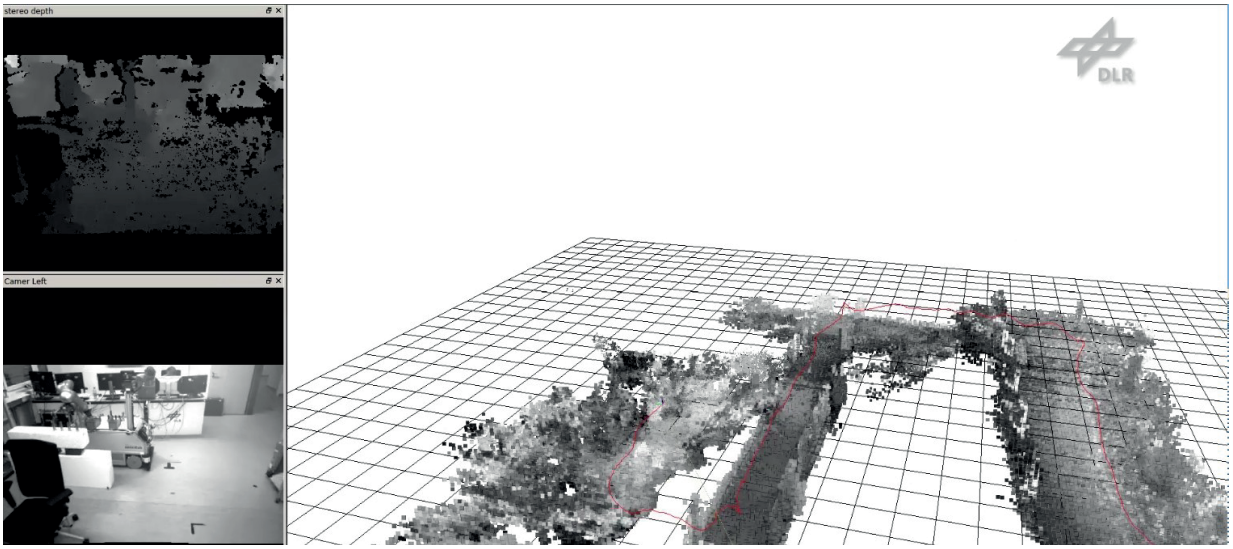


Pelican



# Pelican: Indoor / Outdoor Flight

- Manual flight
- On board processing of SGM, VO, fusion, voxel map, etc
- No external tracking
- https://www.youtube.com/watch?v=RNpbxQurpd8




DLR



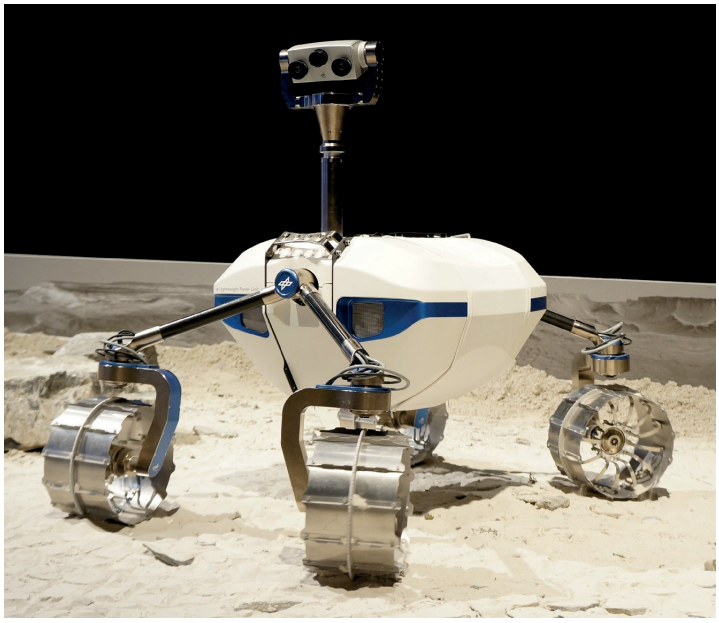
# Pelican: Semi-Autonomous Flight in a Coal Mine

- Operator selected only waypoints
- On board processing of SGM, VO, fusion, map, obstacle avoidance, etc
- No external tracking
- Schmid et al. (IROS 2013, Robocup best paper award)
- https://www.youtube.com/watch?v=hAOf2dA7CNM

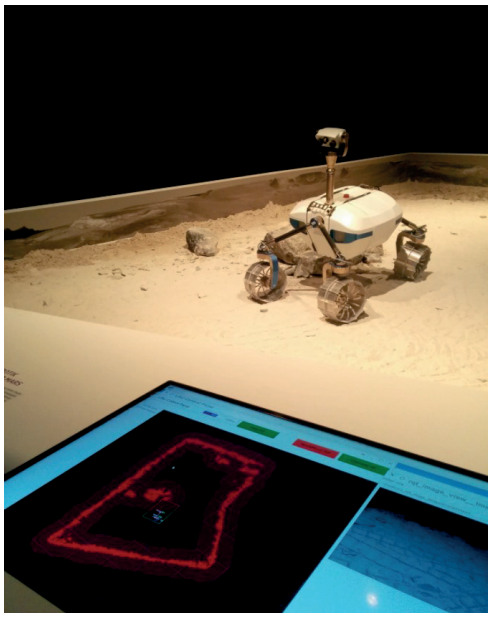

DLR

# Planetary Exploration

Lightweight Rover Unit (LRU)



Demo at ILA 2014

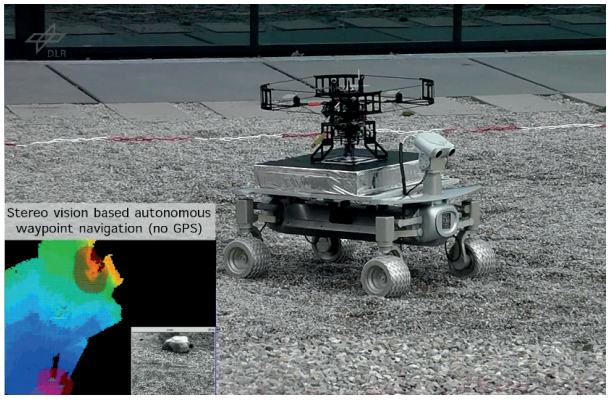






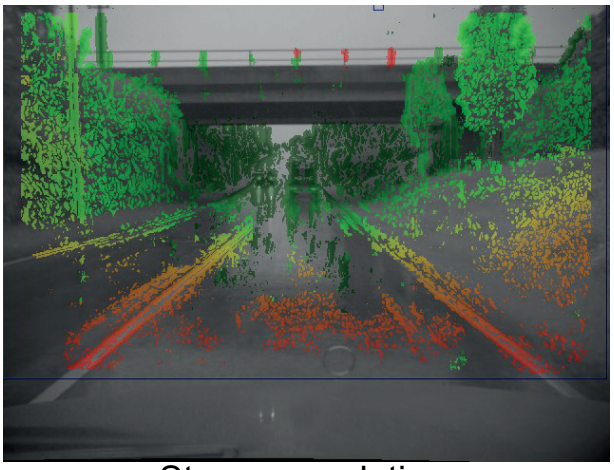
# Rover as Carrier for Quadcopter

- Operator only selects waypoints for rover and quadcopter
- All processing on-board without external tracking or GPS
- https://www.youtube.com/watch?v=dZOmJlWEeFs

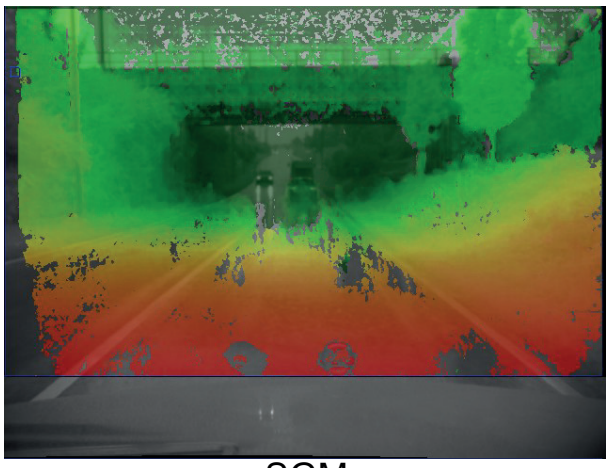



# SGM for Stereo Based Driver Assistance

- Daimler uses own FPGA implementation [Gehrig et al., ICVS 2009]
- SGM used as part of 6D-Vision Systems (www.6d-vision.com)
- Used in E und S class Mercedes since summer 2013



Stereo correlation



SGM

(Images from Stefan Gehrig, Daimler AG)





roboception

# Commercial Perception Solutions

- Roboception GmbH is a DLR spin-off, founded in March 2015 (http://www.roboception.de)

- Offers plug & play real-time perception solutions for robotics
  - Stereo matching
  - Visual odometry (stereo and mono)
  - Fusion with IMU
  - Navigation
  - Object detection and recognition
  - Processing chains for remote sensing
  - etc

- Solutions fulfill hard real time constraints (i.e. work within control loop of robots)

- Bottom up development which considers geometric error as well as confidence at each processing level

roboception

# Innovative Semi-Global Matching with Confidence

- Disparity, geometric error and confidence for every pixel!

DLR