Stereo and Monocular Vision Guidance for Autonomous Aerial and Ground Vehicles

Centro di Ateneo di Studi ed Attivita' Spaziali Giuseppe Colombo - CISAS
Admission to III year

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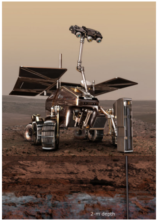
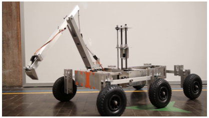
Why vision for navigation?

- Estimate vehicle path when other sources of information are absent (GPS) or unreliable (wheel odometry / inertial navigation)
- Build a consistent 3D map of an unknown environment and localize the vehicle inside it (**SLAM**)
- Plan future motions and identify locations of scientific interest
- Cheap hardware and low mass with respect to the quantity of data available





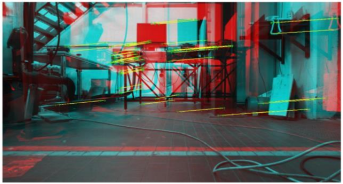
Research Objective: Development of monocular and stereo Visual Odometry and SLAM algorithms that allow unmanned vehicles to perform autonomous exploration. Improving reliability and accuracy solving the following issues:

- Stereo Vision:
  - Failures for low stereo correspondences (presence of occlusions, lighting conditions..)
  - Drift of Visual Odometry estimators for long rover traverses
- Monocular Vision:
  - No metric scale knowledge
  - Reliability: tracking failures, scale drift

Failure mechanisms:

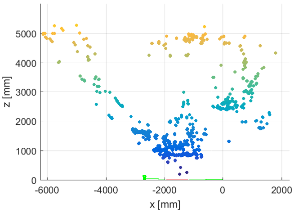
- Excessive proximity of the observed environment
- Obstructions of the FOV of the cameras

Good case: **44** 3D matches

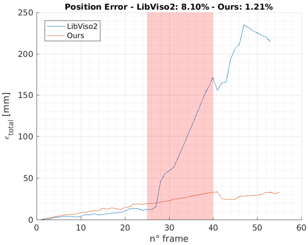


Bad case: **6** 3D matches

- Heuristic to distinguish *good* and *bad* stereo correlations (n tracked 3D points)
- Switch to monocular visual odometry: less baseline between views → better performances
- Our algorithm outperforms current state of the art for stereo Visual Odometry (LibVISO2, A. Geiger et al. 2012)
- todo next → Demonstration of the effectiveness of the approach in real or simulated planetary-like scenarios



Top view of the observed environment



Position estimation error

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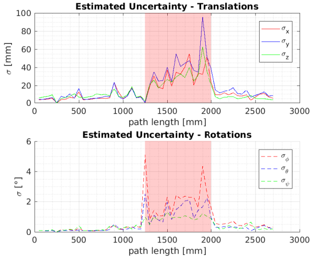
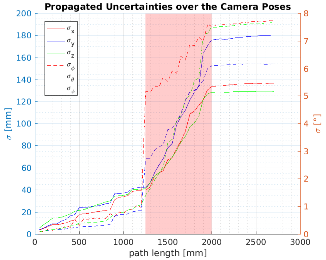
- Red overlay: switch to monocular approach
- Uncertainty estimated using a Monte Carlo approach from inputs: $\sigma_{CAMERA\ PARAMETERS}$ and $\sigma_{FEATURE\ DETECTION}$
- Monocular approaches enhance the robustness of stereo visual odometry in presence of failure situations. However the increase in the estimated uncertainty is significant





- Existing work in literature suggests that stereo visual odometry errors are biased on the landmark spatial distribution. Other bias sources are inaccuracies in camera calibration and distortion removal. We propose a machine learning approach to predict the error in a VO step.
- Predict: 6 motion parameters (3 translations + 3 rotations)
- Predictors: {landmark depth, feature distribution, direction optical flow}
- Predictors are agnostic of the VO algorithm. Only dependency is on the stereo measure

Figure: Green shade: feature density. Red lines: direction of the mean optical flow. Image from KITTI automotive benchmark

Machine learning technique used: Gaussian Process regression.

- Training phase performed with Differential GPS and IMU reference trajectory and orientations
- Predicted errors are subtracted to each VO estimate
- Resulting trajectories are significantly more accurate
- todo next →: evaluation in planetary-like scenarios from datasets or simulations. **Unsupervised** training procedure based on SLAM techniques.

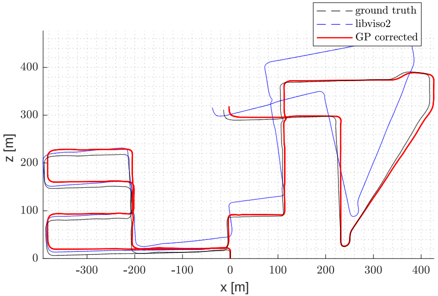


Figure: Blue line is LibVISO2 raw estimate. Red line is LibVISO2 corrected estimate from the error predictions. Black line is the DGPS reference trajectory

Why monocular vision for UAV exploration?

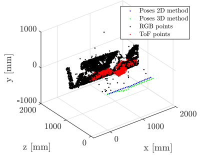
- Single camera $\rightarrow$ miniaturization: low cost, mass and power requirements
- Improve perception of a ground vehicle by collaborative SLAM
- Single camera can be used for orhomosaics and surface reconstruction

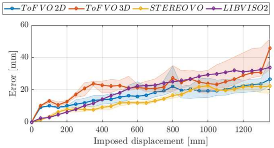
Challenges:

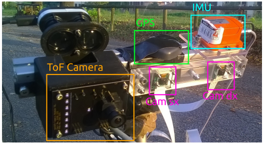
- Monocular vision loses depth information
- 3D reconstruction of environment and ego-motion **up to scale**
- High FPS required to provide localization to an UAV $\rightarrow$ **efficient code**
- No fully working and reliable method in literature up to now

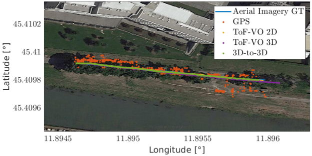
Monocular Visual Odometry aided by a Low Resolution Time of Flight Camera (8x8 pixels @ 20Hz):

- Feasibility study for integrating range measurements in an RGB Visual Odometry algorithm
- Offline Visual Odometry integrating range data in a non-linear optimization of the observed map and camera poses (Local Bundle Adjustment)
- Results show **comparable performances** with a stereo setup









Monocular Vision: Retrieving Scale II

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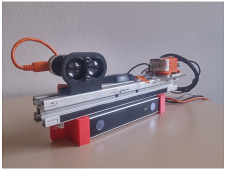
"Scale Correct Monocular Visual Odometry using a LiDAR altimeter" (to be presented at IROS2018):

- Real time pose estimation and mapping (>30Hz)
- Low computational power requirements: **1 range measurement** per keyframe

Completed tasks:

- ✓ Real-time Visual Odometry using USB camera
- ✓ Non-linear optimization of path and map including altimetric measurements
- ✓ ROS (Robot Operating System) nodes for interface and synchronization of images and altimeter
- ✓ Indoor and outdoor tests



Monocular Vision: Retrieving Scale III

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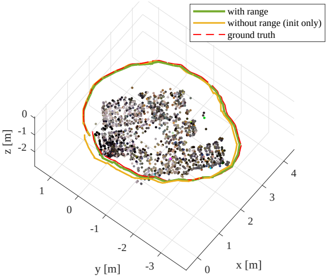
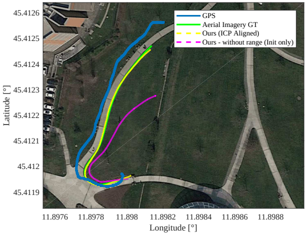
Test in RGBD Dataset with accurate ground truth (left):

- Performances on par with RGB-D Visual Odometry algorithms (*per-pixel* depth information)
- Scale consistency inclusion in optimization background reduces scale drift and increases pose estimation accuracy

Test in outdoor environments with aerial ground truth (right):

- Performances on par with state of the art stereo visual SLAM





$\bar{\varepsilon}_{ALTI} = \mathbf{0.46\%}$ $\bar{\varepsilon}_{NOALTI} = 0.76\%$ $\bar{\varepsilon}_{LENGTH} = \mathbf{1.03\%}$

Monocular SLAM: Retrieving Scale IV

Timings are acceptable for real time operations:

- FPS > 30
- Average time for optimization 100 ms (in a second thread)
- todo next $\rightarrow$ performance optimization and code debugging for enhanced timings and lower resource usage ("spikes" in timings plot)

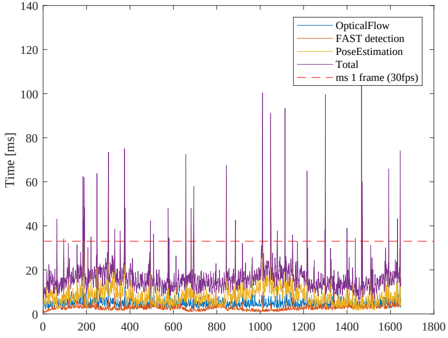


Figure: Timings for main computational thread (feature detection and tracking, pose estimation and map building)

Monocular SLAM: Video

In conclusion:

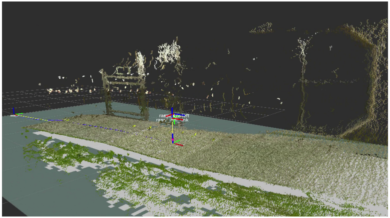
- Stereo visual odometry failures can be efficiently mitigated using monocular approaches
- Stereo visual odometry drift can be learned and predicted
- Scale information can be provided to monocular SLAM using range sensors with a low data volume

Next:

- Algorithm *optimization*, bug removal, timing improvement
- Extensive *testing* on captured and online datasets
- Integration of a *dense reconstruction* background for orthomosaicing
- GPU implementation of algorithm subsections on GPU with CUDA C++ programming
- Code implementation on *embedded platforms* for mobile robotics (nVidia Jetson TX2)

MORPHEUS 2.0: Field Robotics Testbed

Mechanical Configuration



Stereo SLAM test

- Mars like rover designed by a team of students
- Testbed for soil sampling and for autonomous navigation in unknown environments

- Training platform for the astronauts during the Pangaea-X extension campaign

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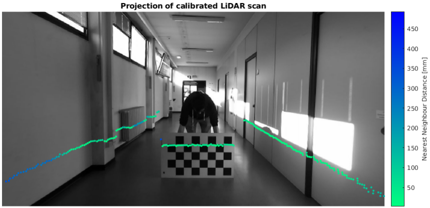
- LiDAR and stereo camera allow map building and autonomous navigation from SLAM techniques
- Extrinsic calibration of the stereo camera and LiDAR system



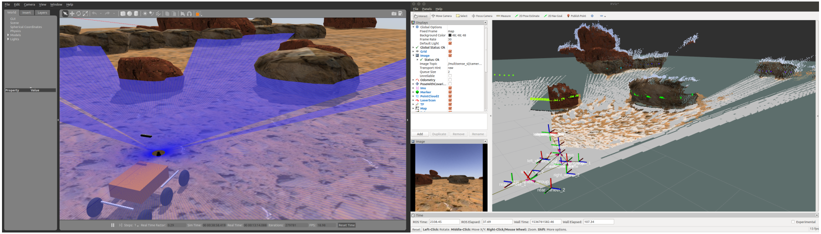
Calibration of the lidar-camera extrinsics

MORPHEUS rover with LiDAR and stereo camera

MORPHEUS 2.0: simulation environment

Physical simulation environment for all the rover operations using ROS (Robot Operating System) and GAZEBO7 environment:

- The simulation communicates with the user using the same commands and code structures of the actual rover
- Test *autonomous navigation* and *obstacle avoidance* software to be used onboard the rover
- Test *research code* controlling illumination, texture and structure of the environment



- **Riccardo Giubilato**, Sebastiano Chiodini, Marco Pertile, Stefano Debei: *Scale Correct Monocular Visual Odometry using a LiDAR altimeter*. International Conference on Intelligent Robots and Systems (to be presented at IROS), 2018 IEEE
- **Riccardo Giubilato**, Sebastiano Chiodini, Marco Pertile, Stefano Debei: *An experimental comparison of ROS-compatible stereo visual SLAM algorithms for planetary rovers*. Metrology for Aerospace (MetroAeroSpace), 2018 IEEE
- **Riccardo Giubilato**, Marco Pertile, Stefano Debei: *A comparison of monocular and stereo visual FastSLAM implementations*. Metrology for Aerospace (MetroAeroSpace), 2016 IEEE
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- Sebastiano Chiodini, **Riccardo Giubilato**, Marco Pertile, Stefano Debei: *Monocular visual odometry aided by a low resolution time of flight camera*. 2017 IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace)
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- Marco Pertile, Sebastiano Chiodini, **Riccardo Giubilato**, Mattia Mazzuccato, Andrea Valmorbida, Alberto Fornaser, Stefano Debei, Enrico Lorenzini: *Metrological Characterization of a Vision-Based System for Relative Pose Measurements with Fiducial Marker Mapping for Spacecrafts*. Journal of Robotics, 2018
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