Automatic Information and Safety Systems for Driving Assistance

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Introduction

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- Economic impact
  - Costs between 1% and 3% of the GNP
  - Overall 500 billion US dollars per year
- A concern of **UN**, **WHO**, **EU**, ...
  - *Reducing road casualties and fatalities will reduce suffering, unlock growth and free resources for more productive use*

Motivation and Objectives

- Technology onboard vehicles
- Positive impact
- Technologies at an early stage of development
- Global description of the scene
- High level understanding
- Asynchronous, large size, multi-modal data

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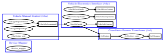
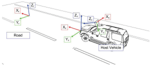
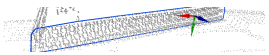
Objective to develop alternative data representations that may cope with multiple sensors and that improve the effectiveness of subsequent processing algorithms

Contributions

- 3 Robot Prototypes
  - Developed three robotic prototypes
  - Autonomous Driving Competitions
- 4 Software Architectures
  - CARMEN, ROS and LARtk
- 5 Inverse Perspective Mapping
  - Proposed a multi-modal, multi-camera IPM
- 6 Photometric Calibration
  - Proposed three approaches for color correction
- 7 Datasets and Preprocessing
- 8-9 Geometric Reconstruction and Refinement
- 10-11 Photometric Reconstruction and Refinement







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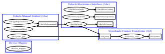

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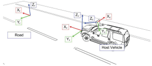

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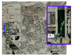

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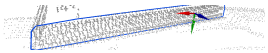

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Scene Reconstruction

- The computation of a (textured) geometric 3D model

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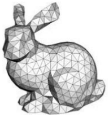
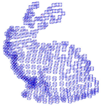


- Volumetric occupancy representations
  - Occupancy grids, (extended) elevation maps or octrees
  - inaccurate geometric information, no texture mapping
  - Robotics



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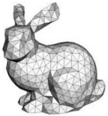

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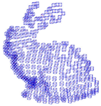
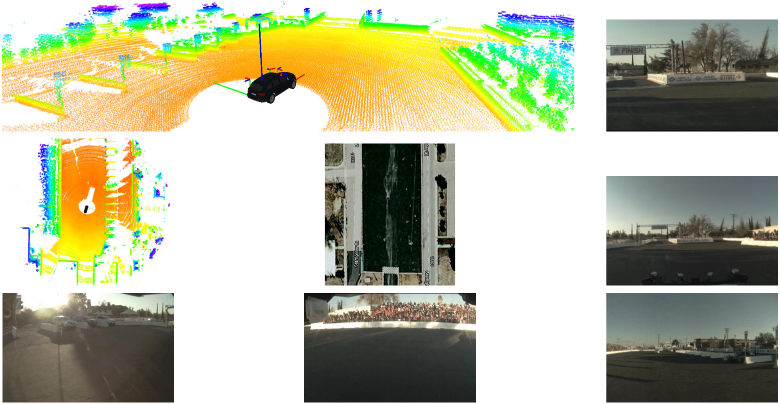


MIT DARPA Urban Challenge dataset

Path travelled by the robot during sequence 1. Key locations are annotated both in the map and the zoomed in image

Location *C* will be used as case study

Raw data captured by the vehicle



Raw data acquired by the vehicle at location C of the sequence 1

Sequence 1 raw data

Only the latest *Velodyne* scan is shown

Continuity

Range measurements are always a discretized view of the environment

Uniqueness

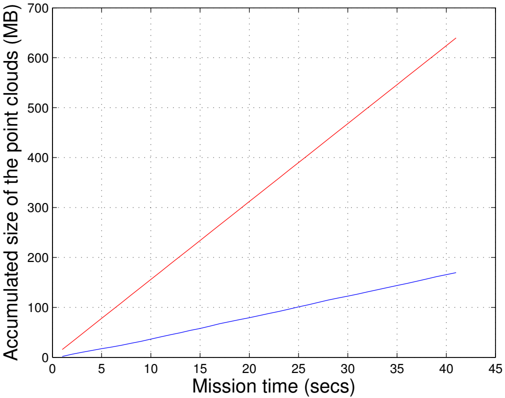
Over time, there are multiple measurements of the same surfaces

Memory efficiency

pt, number of points; size, memory size (MB); t, mission time (secs); d, traveled distance (meters)

Location	Location Snapshot		Sequence accumulated			
Name	pt ($\times 10^6$)	size (MB)	pt ($\times 10^6$)	size (MB)	t (s)	d (m)
A	1.3	15.6	1.3	15.6	1	0
B	1.3	15.6	13.0	156.0	11	75
C	1.3	15.6	26.0	312.0	21	125
D	1.3	15.6	39.0	468.0	31	140
E	1.3	15.6	52.0	624.0	41	190

Compression using Preprocessing



Size of the accumulated point clouds using raw (red) and preprocessed data (blue) as a function of the mission time

Geometric scene reconstruction

- Use a surface based representation

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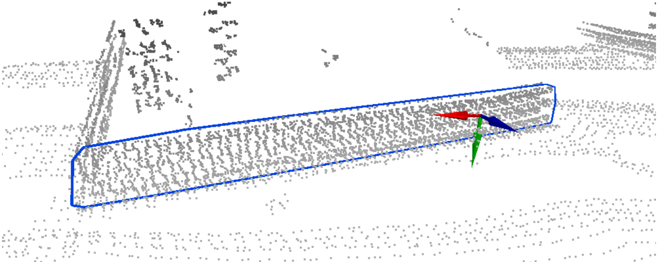
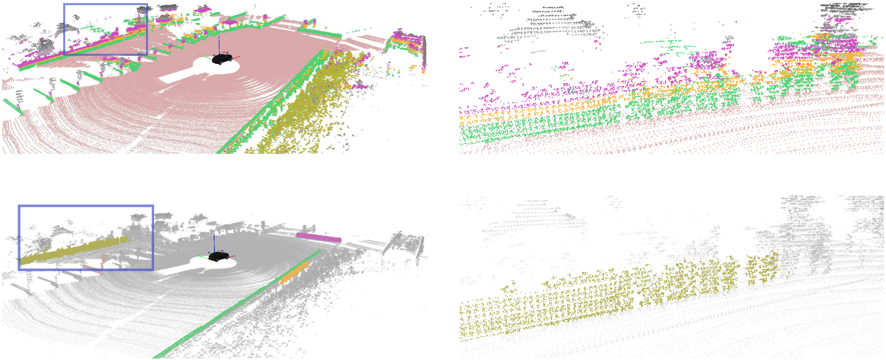


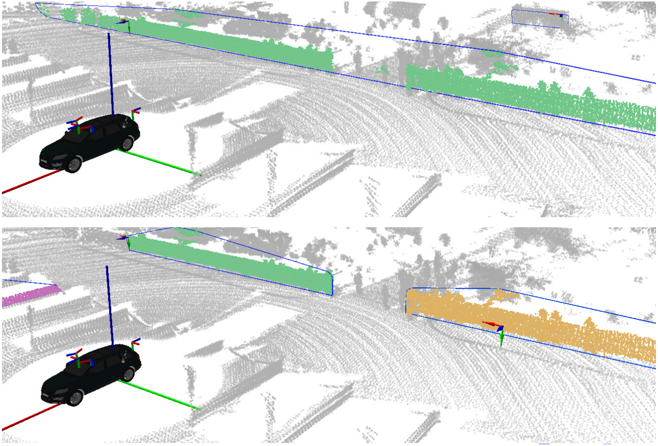
RANSAC

- STEP 1 - Detect candidate polygonal primitives using RANSAC



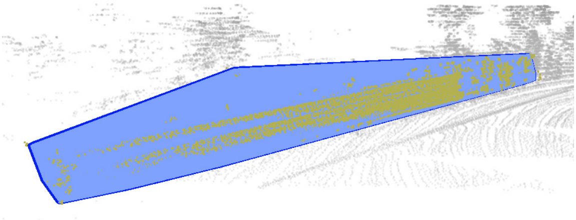
Clustering

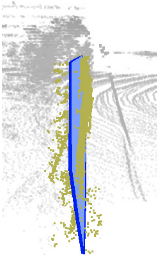
- STEP 2 - Cluster RANSAC inliers



Plane Estimation

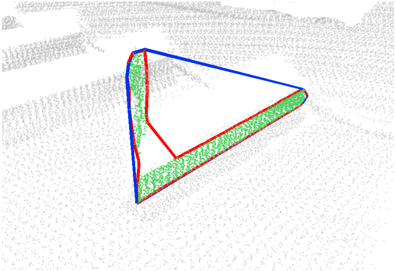
- STEP 3 - Reestimate plane coefficients using PCA

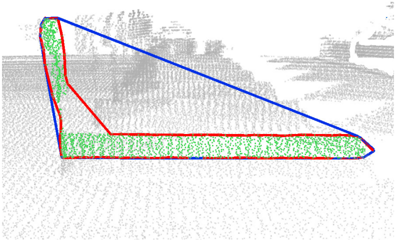




Compute bounding polygon

- STEP 4 - Compute bounding polygon





Convex hull (blue), concave hull (red)

Processing time

	Processing time (secs)				
Location	**BPA**	**GT**	**POIS**	**GPP1**	**GPP2**
A	659.0	154.0	63.2	16.3	27.3
B	752.9	157.5	61.6	25.3	17.4
C	488.2	156.3	56.3	13.5	49.4
D	480.4	142.4	52.6	25.2	25.2
E	558.8	149.0	57.9	47.4	58.1
μ	585.9	151.8	58.3	25.5	35.5

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- **GPP1** 2 times faster than **POIS**
- **GPP1** 6 times faster than fastest 3D triangulation (**GT**)

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- **GPP**1 2 times faster than **POIS**
- **GPP**1 6 times faster than fastest 3D triangulation (**GT**)
- **BPA** is used as ground truth for measuring accuracy

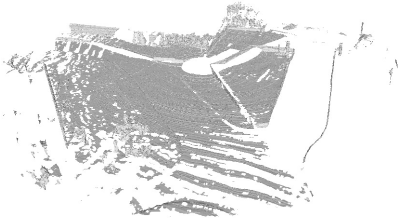
Accuracy

Location	Hausdorff distance (meters)								
	GT			**POIS**			**GPP** 1		
	max	mean	RMS	max	mean	RMS	max	mean	RMS
A	11.7	0.15	0.41	14.0	1.39	2.98	7.6	1.02	1.71
B	11.8	0.12	0.37	14.1	1.39	2.99	12.7	0.94	1.77
C	12.7	0.18	0.44	13.9	1.06	2.59	8.9	0.87	1.54
D	13.8	0.10	0.40	13.9	1.90	4.00	7.6	0.86	1.47
E	12.5	0.14	0.49	14.0	1.42	3.03	14.0	1.25	2.56
μ	12.5	0.14	0.42	13.9	1.43	3.12	10.2	0.99	1.81

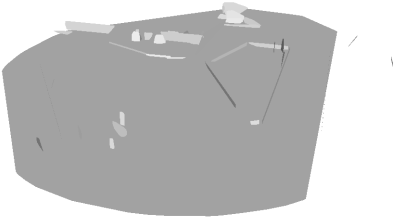
- $0.99 \simeq 1$ meter average error seems to be very large
- However ...

Accuracy

Ground truth (**BPA**)

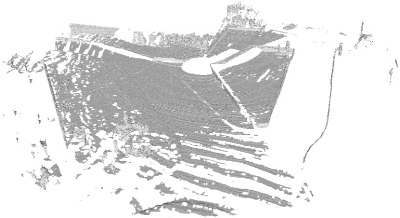


GPP1

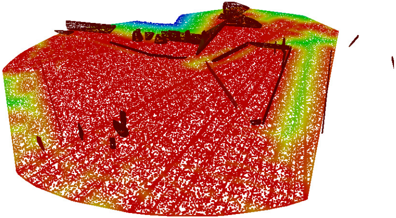


Accuracy

Ground truth (**BPA**)



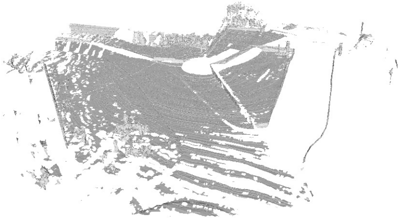
GPP1



- Zero error (red), medium error (green), large error (blue)

Accuracy

Ground truth (**BPA**)



GPP1

- Zero error (red), medium error (green), large error (blue)
- Use <u>concave hull</u> and ground plane <u>not included</u>

Accuracy

B. Polygon Ground plane	**GPP** 2 Hausdorff distance (meters)							
	Convex Included		Convex Not included		Concave Included		Concave Not included	
	max	mean	max	mean	max	mean	max	mean
A	7.6	0.87	1.8	0.15	6.8	0.71	1.2	0.13
B	12.6	0.81	1.5	0.11	12.6	0.53	1.1	0.08
C	8.9	0.69	1.9	0.16	6.6	0.52	1.9	0.12
D	7.6	0.69	2.2	0.14	7.3	0.59	2.1	0.11
E	14.0	1.11	1.7	0.10	8.8	0.32	1.4	0.08
μ	10.1	0.83	1.8	0.13	8.4	0.53	1.5	0.10

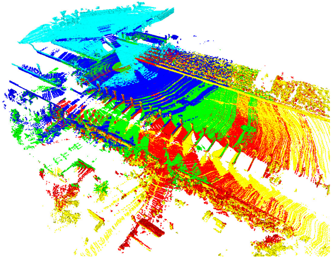
- 0.10 average error better than all others
- **GT** had 0.14 average error

Qualitative results

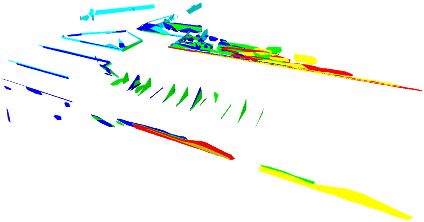
Geometric scene refinement

- How to handle repeated measurements of the same surface?

BPA



GPP



Color notation: reconstruction at locations A, B, C, D and E

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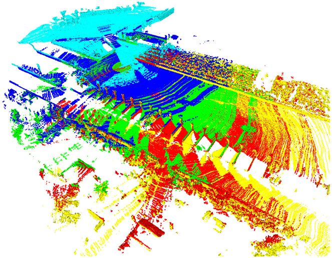
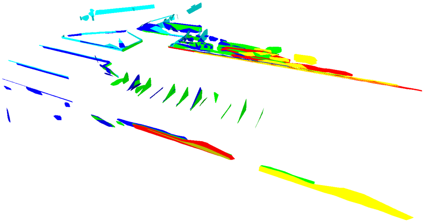


GPP

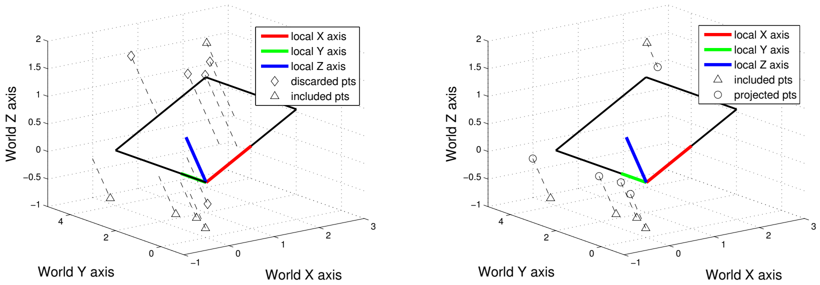


Color notation: reconstruction at locations A, B, C, D and E

- GPP expansion mechanism
  - Faster than (re) detection
  - Save computation time for the detection of novel data

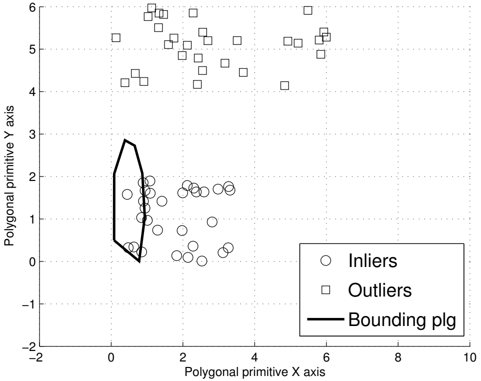
Perpendicular expansion

- STEP 1: to find points have a smaller than T perpendicular distance to the GPP's support plane



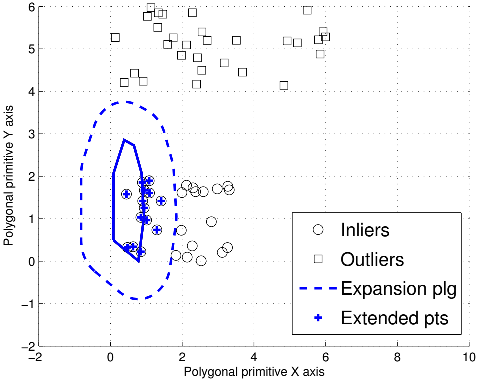
Longitudinal expansion

- STEP 2: Expand the bounding polygon iteratively
- Initial situation



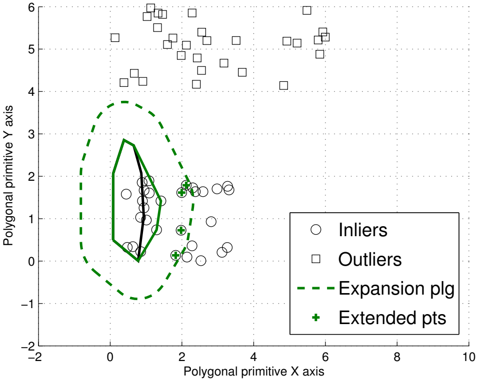
Longitudinal expansion

- STEP 2: Expand the bounding polygon iteratively
- Iteration 1



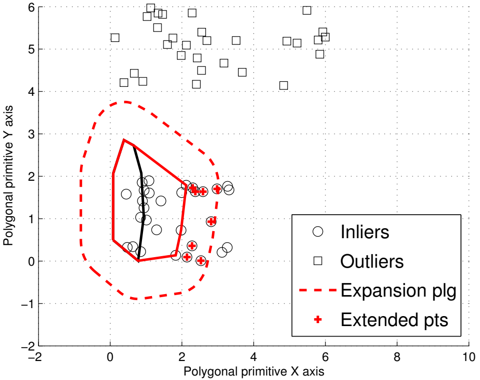
Longitudinal expansion

- STEP 2: Expand the bounding polygon iteratively
- Iteration 2



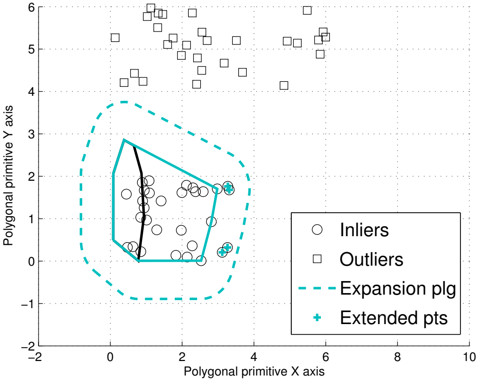
Longitudinal expansion

- STEP 2: Expand the bounding polygon iteratively
- Iteration 3



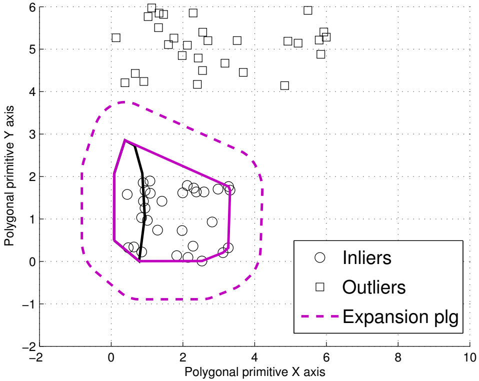
Longitudinal expansion

- STEP 2: Expand the bounding polygon iteratively
- Iteration 4



Longitudinal expansion

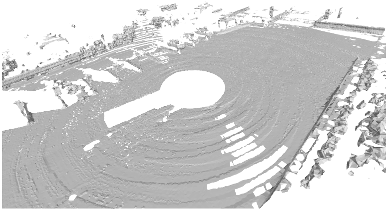
- STEP 2: Expand the bounding polygon iteratively
- Iteration 5

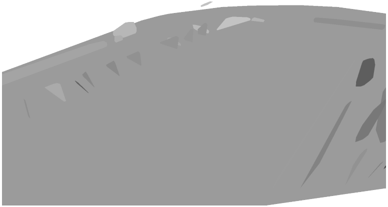


Qualitative results

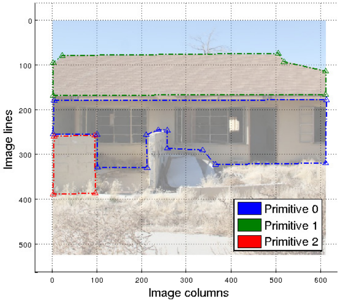
Photometric scene reconstruction

- How to add texture to the **GPP**?
- Classical approaches use the (3D) triangulated mesh
- Proposed approach is to triangulate in the image space (2D)
- Accurate texture mapping - **DDT**

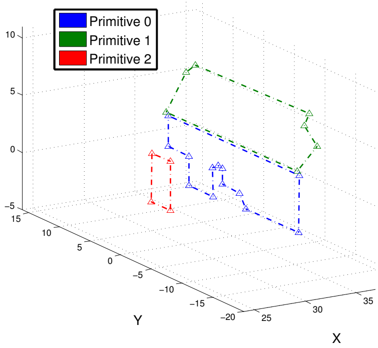




A single image mapping multiple primitives



Primitives in image space



Primitives in 3D space

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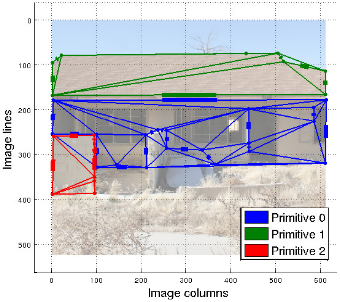
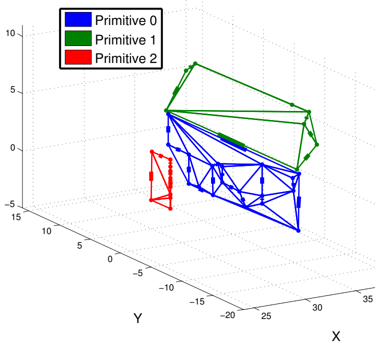


Mesh in image space



Mesh in 3D space

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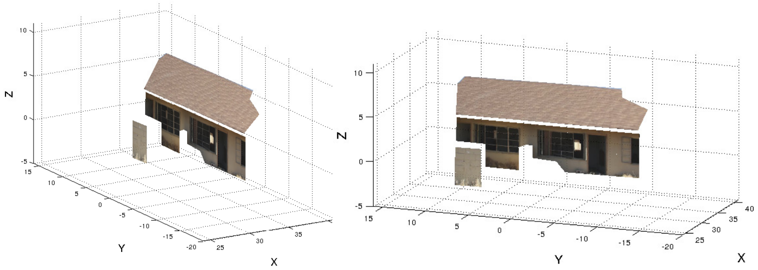
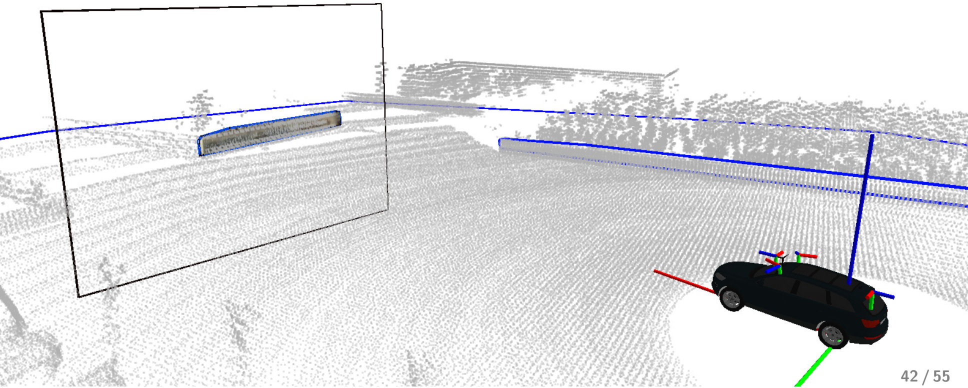


Textured primitives

Photometric scene refinement

- What happens if two images map to the same region of a primitive?
- Or if a primitive is textured with an image I_0 at time t_0, but at t_1 there is a better I_1?



Photometric scene refinement

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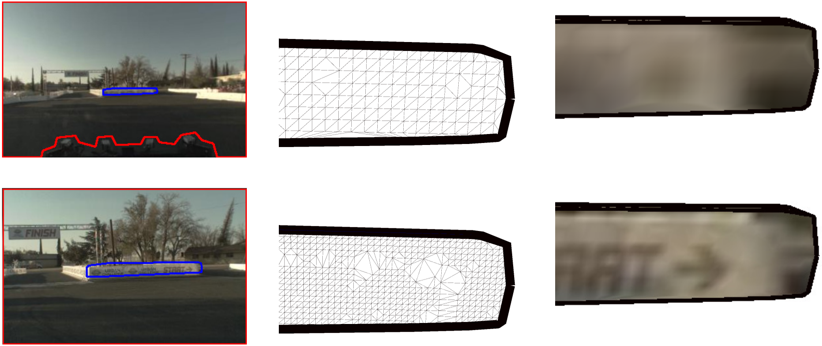
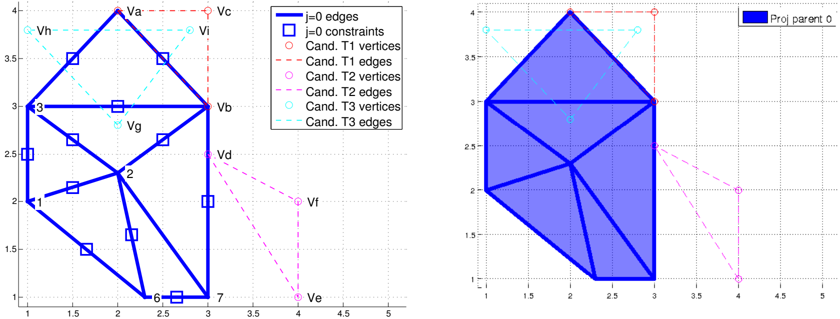


Proposed approach

- Sequential updating of the Global Primitive Mesh
  - A mosaic of local image meshes from different projections
  - Composed of parent and orphan triangles
  - Heavily CDT



Add red triangle, then magenta, then cyan

Proposed approach

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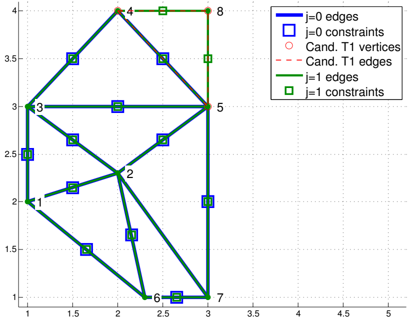
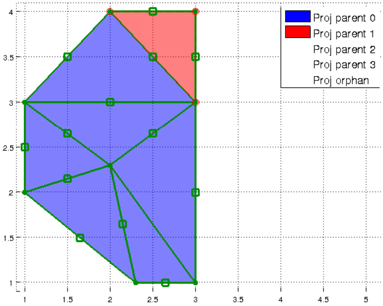
  - A mosaic of local image meshes from different projections
  - Composed of parent and orphan triangles
  - Heavily CDT





After adding red triangle

Proposed approach

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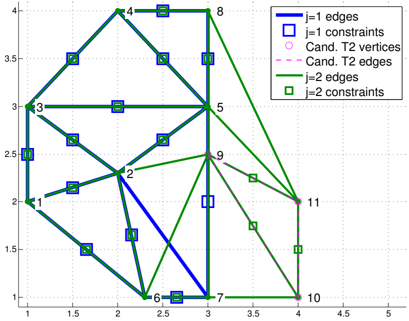
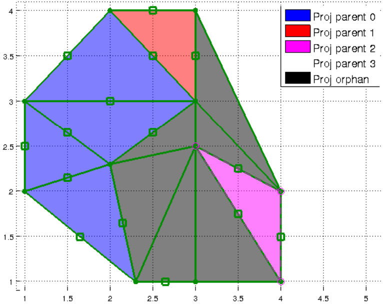
  - Heavily CDT





After adding magenta triangle

Proposed approach

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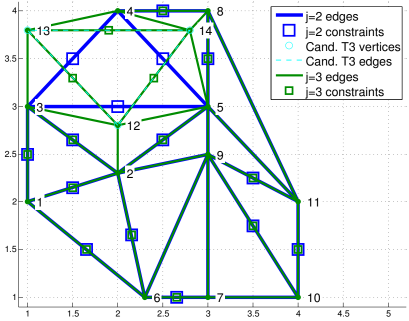
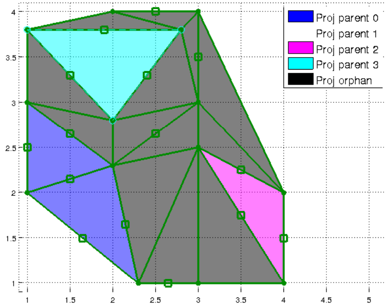
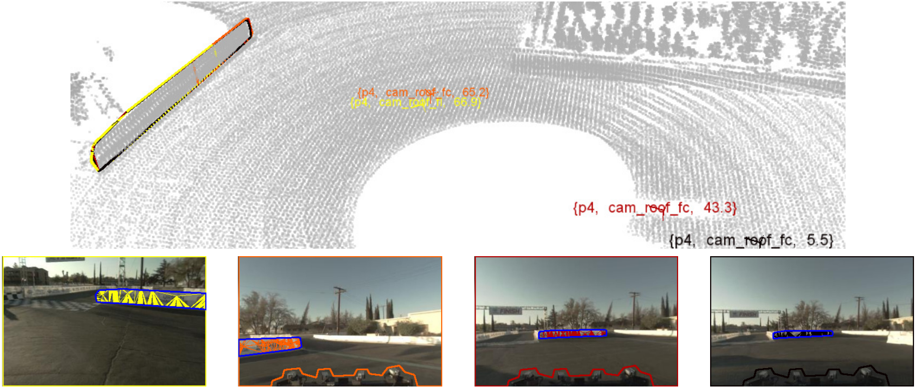




After adding cyan triangle

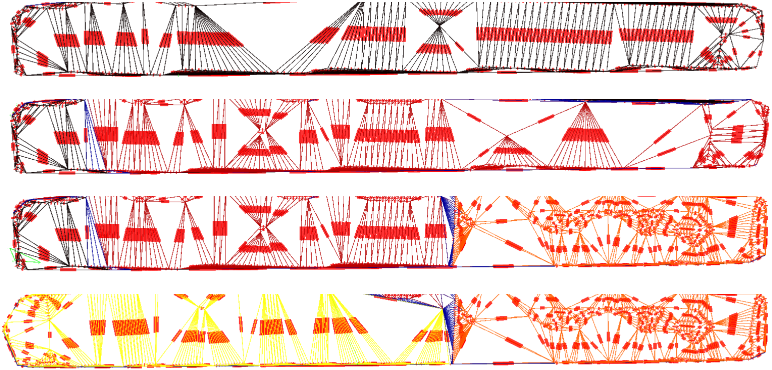
A case study



Global primitive mesh is updated with projections black, red, orange and yellow

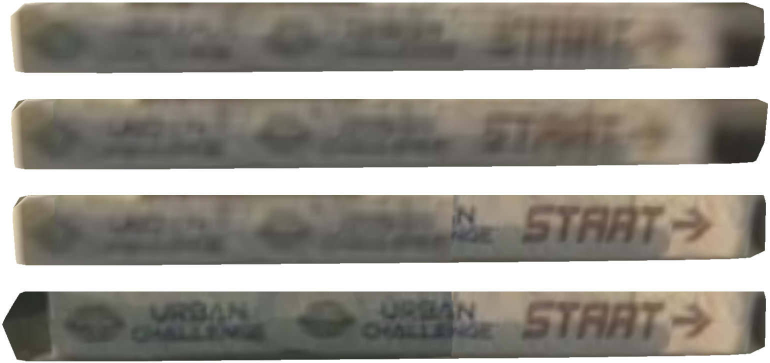
Vehicle moves from right to left

A case study



Blue triangles are orphan triangles

A case study



Qualitative results

Publications

Miguel Oliveira and Vitor Santos. Multi-camera active perception system with variable image perspective for mobile robot navigation. In Portuguese Robotics Open 2008, International Conference on Autonomous Robot Systems and Competitions, April 2008. Best conference paper award. Selected for publication in Robótica (ISSN 0874-9019), published in number 76, September 2009

Miguel Oliveira, Procopio Stein, Jorge Almeida, and Vitor Santos. Modular scalable architecture for the navigation of the atlas autonomous robots. In Portuguese Robotics Open 2009, International Conference on Autonomous Robot Systems and Competitions, April 2009

Vitor Santos, Jorge Almeida, Emanuel Avila, David Gameiro, Miguel Oliveira, Ricardo Pascoal, Remi Sabino, and Procopio Stein. Atlascar - technologies for a computer assisted driving system on board a common automobile. In 13th International IEEE Conference on Intelligent Transportation Systems, pages 1421 - 1427, September 2010.

Miguel Oliveira and Vitor Santos. Autonomous driving competition: Perception approaches used in the atlas project. In Portuguese Robotics Open 2011, International Conference on Autonomous Robot Systems and Competitions, April 2011.

Miguel Oliveira, Angel D. Sappa, and Vitor Santos. Unsupervised local color transfer for coarsely registered images. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, pages 201-208, June 2011.

Miguel Oliveira, Vitor Santos, and Angel D. Sappa. Short term path planning using a multiple hypothesis evaluation approach for an autonomous driving competition. In IROS Workshop on Planning, Perception and Navigation for Intelligent Vehicles, October 2012.

Miguel Oliveira, Angel D. Sappa, and Vitor Santos. Color correction using 3d gaussian mixture models. In ICIAR (1), pages 97-106, June 2012.

Miguel Oliveira, Angel D. Sappa, and Vitor Santos. Color correction for onboard multi-camera systems using 3d gaussian mixture models. In Intelligent Vehicles Symposium, pages 299-303, 2012.

Miguel Almeida, Paulo Dias, Miguel Oliveira, and Vitor Santos. 3d-2d laser range finder calibration using a conic based geometry shape. In ICIAR (1), pages 312-319, 2012.

Conclusions

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  - Accurate texture mapping (**DDT**)
- Photometric refinement
  - A mechanism to make texture evolve over time
  - Texture is improved if new better images are received

Future Work

- Speed up processing
- How can a model of the environment be used for improving
  - Pattern recognition
  - Navigation
  - The understanding what other agents in the scene

Thank You