Technical University of Cluj-Napoca

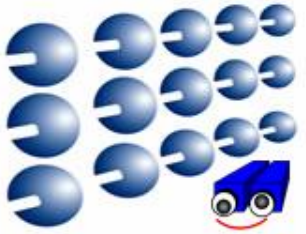
Romania

Image Processing and Pattern Recognition Centre

Prof. dr. eng. Sergiu Nedevschi

Sergiu.Nedevschi@cs.utcluj.ro

http://cv.utcluj.ro



Areas of Expertise

Image processing and pattern recognition:

- **Image acquisition systems**: setting up imaging solutions using digital and analogue cameras and frame-grabbers, multiple cameras synchronization, adaptation to lighting conditions.
- **Color, grayscale and 3D image processing:** filtering, analysis and image noise removal, feature extraction, textural analysis, segmentation, etc.
- **Stereovision:** 3D reconstruction by analysis of synchronized image pairs. This domain involves camera parameter computation through accurate calibration, image rectification, feature matching in multiple images, 3D computation using sub-pixel accuracy, post-processing.
- **Dense optical flow:** use of variational methods for dense, accurate optical flow computation for real life scenarios.
- **Object detection, classification and tracking:** use of probabilistic model-based techniques for extraction of relevant objects' parameters from the 3D, grayscale and color information. Use of classifiers and probabilistic estimators for object type identification and object parameter tracking.
- **Real-time computer vision:** image processing algorithms optimization using parallelization techniques and exploiting modern computing architectures, such as GPUs and FPGAs.

Areas of Expertise

Applications in:

- **Stereovision based sensorial perception:** organization, identification and interpretation of the sensory information for environment representation and understanding.
- **Advanced driving assistance and Autonomous mobile systems:** environment perception and representation, risk assessment, planning
- **Medical image analysis:** use of texture analysis, probabilistic segmentation methods, and machine learning solutions for automatic or computer assisted diagnosis.

Team

Coordinator: Prof. Dr. Eng. Sergiu NEDEVSCHI

Assist. Prof. Dr. Eng.Tiberiu Mariţa
Assist. Prof. Dr. Eng. Radu Dănescu
Assist. Prof. Dr. Eng. Florin Oniga
Assist. Prof. Dr. Eng. Delia Mitrea
Assist. Prof. Dr. Eng. Cristian Vicas

Assist. Dr. Inf. Anca Ciurte
Dr. Eng. Pangyu Jeong
Dr. Eng. Silviu Bota
Dr. Eng. Cosmin Pantilie
Dr. Eng. Voichita Popescu

PhD Student Ciprian Pocol
PhD Student Cristian Vancea
PhD Student Raluca Brehar
PhD Student Mihai Negru

PhD Student Andrei Vatavu
PhD Student Ion Giosan
PhD Student Marius Drulea
PhD Student Arthur Costea
PhD Student Robert Varga
PhD Student Dan Pojar

Master Student Aliz Nagy
Master Student Istvan Szakats
Master Student Adina Mandrut
Master Student Claudiu Cosma

Current Research Topics

- **Stereo Vision Based Environment Perception**
  - Dense Stereo, Dense Optical Flow and Ego Motion Estimation
  - 3D Environment Perception and Representation
  - Sensor Fusion and 3D Representation Refinement
  - High Level Reasoning on Perception and Domain Knowledge
- **Omni-directional Stereo System**
  - Omni-directional Stereo Reconstruction
  - Omni-directional Stereo based Visual Perception
- **Cooperative Driving Assistance Based on Smart Mobile Platforms**

Current Research Projects

- PAN-Robots - Plug And Navigate ROBOTS for smart factories, FP7 project (2012 – 2015)
- Co-operative Mobility Services of the Future - CoMoSeF, Celtic Plus project, (2012-2015)
- Cooperative Advanced Driving Assistance System Based on Smart Mobile Platforms and Road Side Units – SmartCoDrive, grant funded by Romanian Ministry of Education and Research, code PN II PCCA 2011 3.2-0742 din 03.07.2012 (2012-2015)
- Multi-scale multi-modal perception of dynamic 3D environments based on the fusion of dense stereo, dense optical flow and visual odometry information, grant funded by Romanian Ministry of Education and Research, code IDEI 2011, (2012-2014)
- DRIVE C2X, FP7 project (2011-2013)

Previous Research Projects

- INSEMTIVES - Incentives for Semantics, FP7 project (2010 – 2012)
- LarKC - The Large Knowledge Collider, FP7 project (2010 – 2011)
- Sensorial Perception and World Model Representation for Driving Assistance Systems - PERSENS, grant funded by Romanian Ministry of Education and Research, CNCSIS, code 1522/2009, (2009-2011)
- Cooperative Intersection Safety - INTERSAFE -2, FP7 project (2008 – 2011)
- Experimental Low Earth Orbit Surveillance Stereoscope – LEOSCOP, grant funded by Romanian Ministry of Education and Research, CNMP: 82-093 / 2008, (2008-2011)
- Stereo System Modular Design – MODULAR, research project funded by Volkswagen AG, Germany, (2008-2009)
- Dense STEREO-Based Object Tracking and CLASSification for Pre-Crash-Applications - STEREOCLASS, research project funded by Volkswagen AG, Germany, (2008)
- Dense Stereo-Based Object Detection, Tracking and Pedestrian Classification in Traffic environments – DESPED, Volkswagen AG, Germany, (2006-2007)

Previous Research Projects

- The assurance of traceability and quality control in food industry - FOOD-TRACE, grant funded by Romanian Ministry of Education and Research (2006-2008)
- Dense-Stereo based Object recognition for Automatic Cruise Control in Urban Environments – DESBOR, Volkswagen AG, Germany, (2005-2006)
- Intelligent System for Assisting the Therapeutical Decision at Pacients with Prostate Cancer – INTELPRO, grant funded by Romanian Ministry of Education and Research (2005-2008)
- Method and System for Real-time Acquisition of High-resolution 3D Images Based on Trinocular Stereo-vision, grant funded by Romanian Ministry of Education and Research (2004-2006)
- Stereo-Camera Based Object Recognition System for Vehicle Application - SCABOR, Volkswagen AG, Germany, (2001 – 2004)
- SONOFIBROCAST, “A stage diagnosis and prediction algorithm of the liver fibrosis evolution using non invasive ultrasound techniques, optimized by stochastic analysis and image processing”, (2007-2010), Joint Applied Research Project.

Partners

- Volkswagen AG, Germany
- Sick AG, Germany
- University of Braunschweig, Germany
- INRIA Rocquencourt, France
- University Joseph Fourier Grenoble, France
- VTT, Finland
- AROBS, Romania

Infrastructure

- Industrial CCD video cameras, color and grayscale, digitally interfaced and supporting external synchronization.
- Digital image capture devices, capable of synchronizing multiple cameras for binocular or trinocular stereovision.
- Integrated stereo acquisition systems (stereoheads).
- Stereo reconstruction hardware boards.
- Single beam and multi-beam laser scanners.
- High resolution DGPS receivers with 2 cm accuracy.
- Wireless communication interfaces for automotive applications (801.11p standard).
- CAN cards, and CAN monitoring software.
- Mobile platform for driving assistance applications.
- Pioneer 3-ATmobile robot.
- Software development frameworks for stereovision-based applications.
- Software development frameworks for medical imaging.

Achievements

- High accuracy feature-based stereovision
- High accuracy dense stereovision
- High accuracy dense optical flow
- Vision based ego-motion estimation using a stereo system
- Lane detection and tracking
- Detection and classification of painted road objects
- Obstacle detection and tracking
- Obstacle classification
- Perception & representation of unstructured environments
- Forward collision detection
- Dynamic environment perception
- High level reasoning on perception and domain knowledge

Products, Technologies, Patents

Products and Technologies

1. Real-time stereovision-based driving assistance sensorial system for highways, capable of detecting objects in the range of 10 -120 m, to track objects with a relative speed of 180 km/h, and to detect and measure the road lanes.

2. Real-time stereovision-based sensorial system for city driving assistance functions, capable of detecting objects in the range of 0-50 m, in a wide field of view, to track objects having up to 80 km/h relative speed, to detect and track marked and non-marked road lanes, and to recognize object types (cars, pedestrians, bikes, others).

3. Real-time stereovision-based advanced driving assistance for cooperative intersection safety.

4. Real-time GPU based solutions for accurate dense stereovision and accurate dense optical flow estimation from image sequences.

5. Ground-base long baseline observation system for automatic detection and ranging of Low Earth Orbit objects.

6. Automatic visual annotation system

7. Medical diagnosis assistance system based on ultrasonic image texture analysis, for detection of diffuse diseases, malign and benign liver tumours, prostate cancer.

International Patents:

M. Akio, S. Nedevschi, “Optical System”, international patent no. WO2012038601-A1, March 29, 2012

Selected publications

1. S. Nedevschi, V. Popescu, R. Danescu, M. Tiberiu, F. Oniga, “Accurate Ego-Vehicle Global Localization at Intersections through Alignment of Visual Data with Digital Map”, accepted in *IEEE Transactions on Intelligent Transportation Systems,* 2012

2. R. Danescu, F. Oniga, V. Turcu, O. Cristea, “Long Baseline Stereovision for Automatic Detection and Ranging of Moving Objects in the Night Sky”, *Sensors*, vol. 12, no. 10, October 2012, pp. 12940-12963.

3. A. Ciurte, S. Nedevschi, I. Rasa, “An algorithm for solving some nonlinear systems with applications to extremum problems”, *Taiwanese Journal of Mathematics*, vol. 16, no. 3, 2012, pp. 1137-1150.

4. C. Pantilie, S. Nedevschi, “SORT-SGM: Sub-pixel Optimized Real-Time Semi-Global Matching for Intelligent Vehicles”, *IEEE Transactions on Vehicular Technology*, vol. 61, no. 3, 2012, pp. 1032-1042.

5. I. Haller, S. Nedevschi, "Design of Interpolation Functions for Sub-Pixel Accuracy Stereo-Vision Systems”, *IEEE Transactions on Image Processing*, vol. 21, no. 2, 2012, pp. 889-898.

Selected publications

6. C. Vicas, M. Lupsor, M. Socaciu, S. Nedevschi, R. Badea, “Influence of Expert-Dependent Variability over the Performance of Noninvasive Fibrosis Assessment in Patients with Chronic Hepatitis C by Means of Texture Analysis”, *Computational and Mathematical Methods in Medicine*, Article no. 346713, 2012.

7. D. Mitrea, S. Nedevschi, M. Socaciu, R. Badea, “The Role of the Superior Order GLCM in the Characterization and Recognition of the Liver Tumors from Ultrasound Images”, *Radioengineering*, vol. 21, no. 1, 2012, pp. 79-85.

8. R. Danescu, F. Oniga, S. Nedevschi, "Modeling and Tracking the Driving Environment with a Particle Based Occupancy Grid”, *IEEE Transactions on Intelligent Transportation Systems*, Vol.12, Issue 4, pp. 1331 – 1342, 2011.

9. C. Vicas, M. Lupsor, R. Badea, S. Nedevschi, “Usefulness of textural analysis as a tool for noninvasive liver fibrosis staging”, *Journal of Medical Ultrasonics*, Vol. 38, no. 3, 2011, pp. 105-117.

10. F. Oniga, S. Nedevschi, "Processing Dense Stereo Data Using Elevation Maps: Road Surface, Traffic Isle and Obstacle Detection", *IEEE Transactions on Vehicular Technology*, vol. 59, no. 3, 2010, pp. 1172-1182.

Selected publications

11. A. Ciurte, S. Nedevschi, I. Rasa, “A Generalization of the EMML and ISRA Algorithms for Solving Linear Systems”, *Journal of Computational Analysis and Applications*, vol. 12, no. 4, 2010, pp. 799-816.

12. S. Nedevschi, S. Bota, C. Tomiuc, “Stereo-Based Pedestrian Detection for Collision-Avoidance Applications”, *IEEE Transactions on Intelligent Transportation Systems*, vol. 10, no. 3, 2009, pp. 380-391.

13. C. Tomiuc, S. Nedevschi, “Real-time pedestrian classification exploiting 2D and 3D information”, *IET Intelligent Transportation Systems*, vol. 2, no. 3, 2008, pp. 201-210.

14. R. Danescu, S. Nedevschi, “Probabilistic Lane Tracking in Difficult Road Scenarios Using Stereovision”, *IEEE Transactions on Intelligent Transportation Systems*, vol. 10, no. 2, 2009, pp. 272-282.

15. S. Nedevschi, C. Vancea, T. Marita, T. Graf, "Online Extrinsic Parameters Calibration for Stereovision Systems Used in Far-Range Detection Vehicle Applications", *IEEE Transactions on Intelligent Transportation Systems*, vol. 8, no. 4, 2007, pp. 651-660.

Cooperation Offer

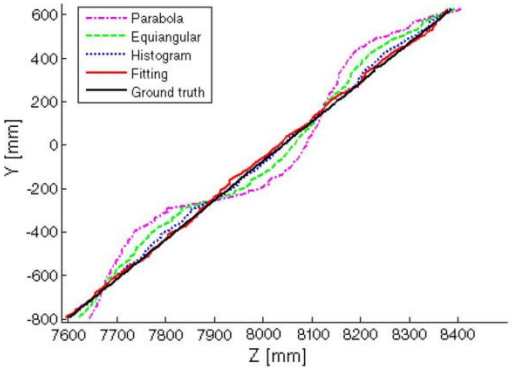
Research & development in core areas	- Development of original solutions for modeling dynamic 3D environments. - Development of original algorithms for feature extraction from monocular grayscale or color images, from stereo images, or from medical images (CT, ultrasonic, PET). - Development of original algorithms for 3D or 6D reconstruction, using classical stereovision, omnidirectional stereovision and optical flow. - Development of original algorithms for model matching, probabilistic tracking, and object classification.
Research & development in applied fields	- Development of real-time perception systems for structured or unstructured 3D environments, applied to driving assistance systems, autonomous robots, space observation, or computer assisted medical diagnosis. - Development of integrated hardware and software solutions for computer vision, with multiple applications. - Development of cooperative driving assistance systems.

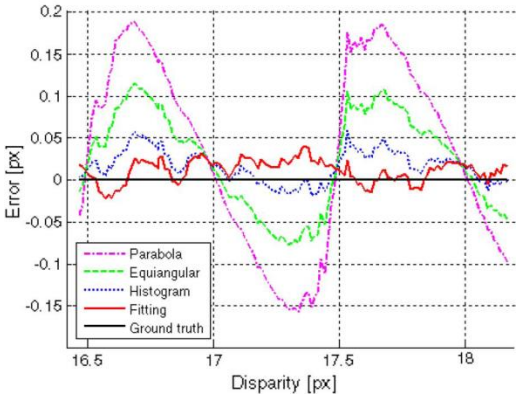
Cooperation Offer

Consulting	Consulting, design, research and prototyping towards development of image processing based solutions for multiple industrial and scientific fields.
Applied engineering services	Custom integrated hardware and software solutions for specific problems related to driving assistance systems, surveillance, object and people recognition, automated medical diagnosis.
Training	**Image processing basics:** camera model, image formation, noise in the digital images, noise removal techniques, edge and corner detection, image segmentation, color spaces, frequency space analysis. **Pattern recognition techniques:** extraction of features for classification, classification techniques, design and use of classifiers, object tracking techniques. **Advanced techniques:** accurate camera calibration, real-time stereovision, real-time optical flow, FPGA based image acquisition and processing.

Stereo reconstruction

- State-of-the-art reconstruction engine featuring
  - High reconstruction density
    - Census-based matching
    - Semi Global Matching (SGM) optimization along 4 directions
  - High reconstruction accuracy
    - Eliminate the so-called “pixel-locking” effect
    - Two original solutions, developed for SGM algorithm
      - Histogram based
      - Function fitting based
  - Real-time on off the shelf GPU (>90 fps)
    - Off-the-shelf hardware
    - Inexpensive compared to commercial stereo reconstruction solutions
    - Performance increases without additional development costs as newer, more powerful, boards become available





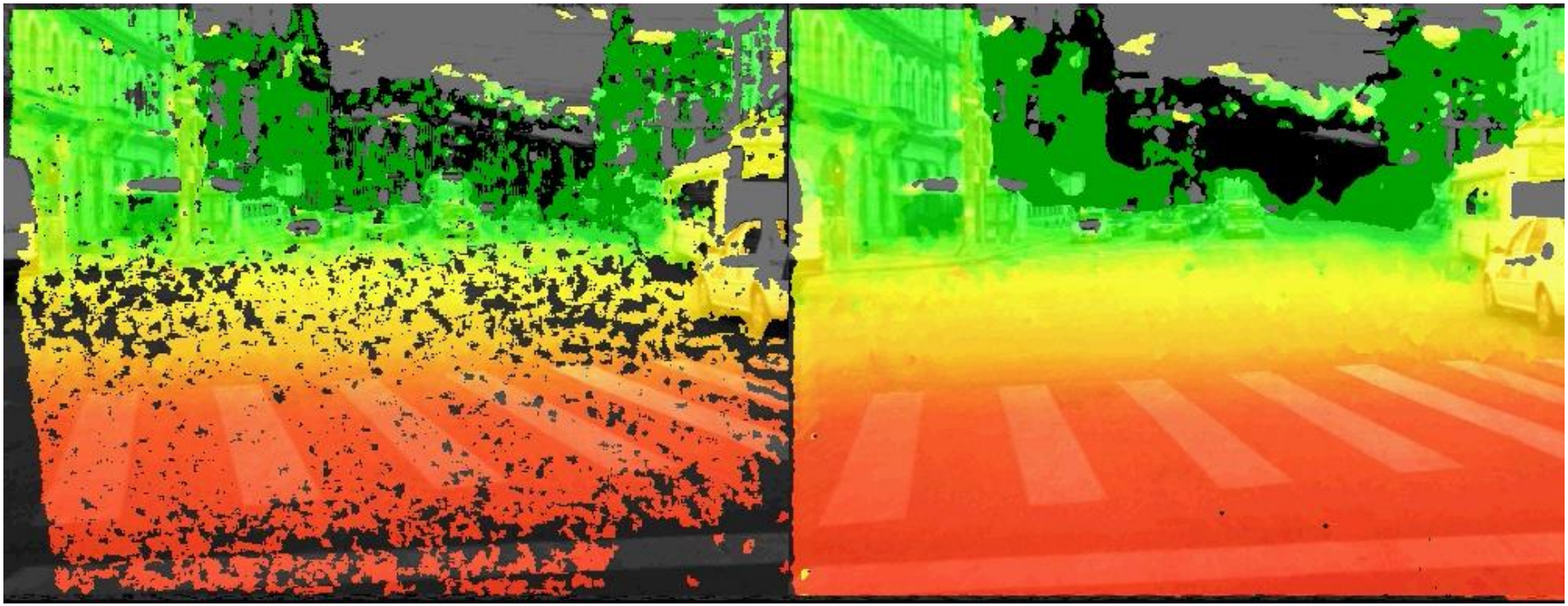
Stereo reconstruction

Near .....Far

Stereo reconstruction

- **Extensions for local refinement of highly untextured areas**
  - **Region based refinement**
    - **QuickShift segmentation of homogeneous areas**
    - **Oversegmenation: smaller patches which can be more accurately approximated by the planar model**
    - **3D planes are fitted from confident matches**
    - **low-textured or low-confidence pixels refined using the computed planes**
  - **Discontinuity preserving interpolation of remaining missing values**

Stereo reconstruction



Near .....Far

High accuracy dense optical flow

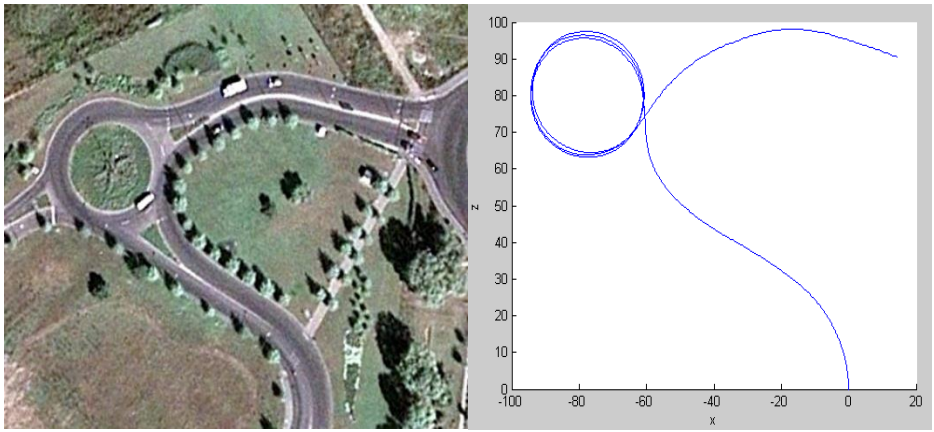
-Robust and discriminative matching function based on a combination of intensities and gradients
-It is able to handle changes of illumination
-Non-local propagation of the flow, guided by bilateral filtering
-Use robust statistics to preserve motion discontinuities
-Fast estimation by means of convex optimization
-Real time on GPU: 35 fps

- INTERSAFE-2 (Cooperative Intersection Safety 2, FP7 Project)
- PERSENS (Sensorial Perception, Modeling and Representation of the World Model for Driving Assistance Systems, National Project)

High accuracy dense optical flow

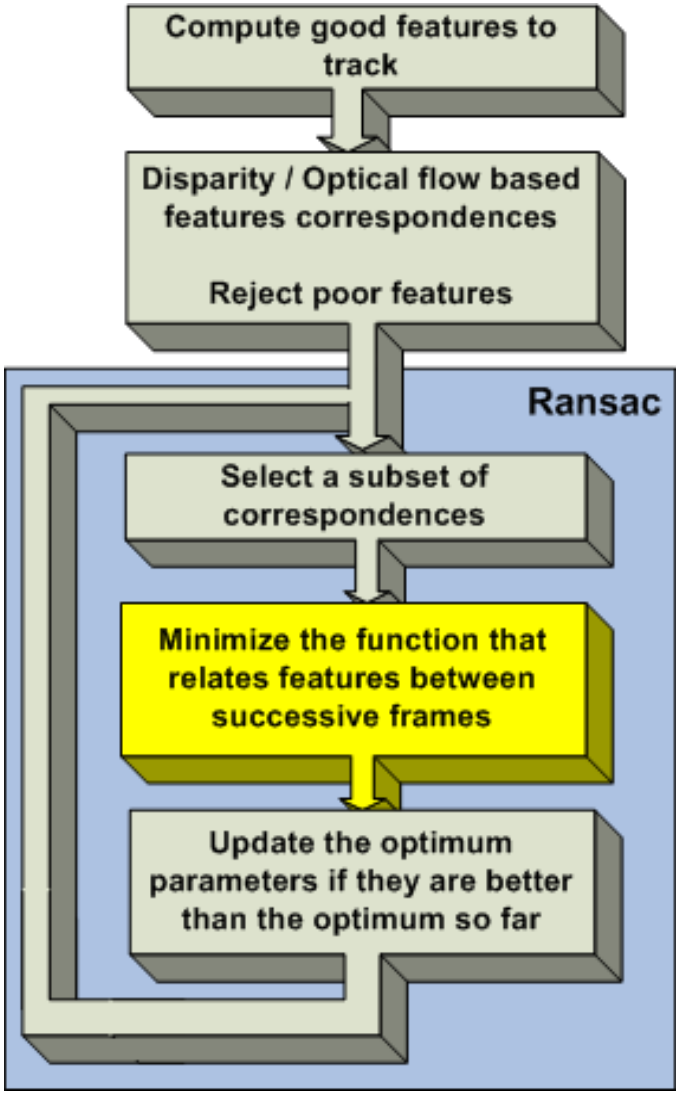
Vision based ego-motion estimation using a stereo system

- Traditional localization methods (GPS, IMU) can be imprecise or costly.
- Estimating the movement of a stereo camera is an attractive alternative to classical localization sensors and gives very good results.

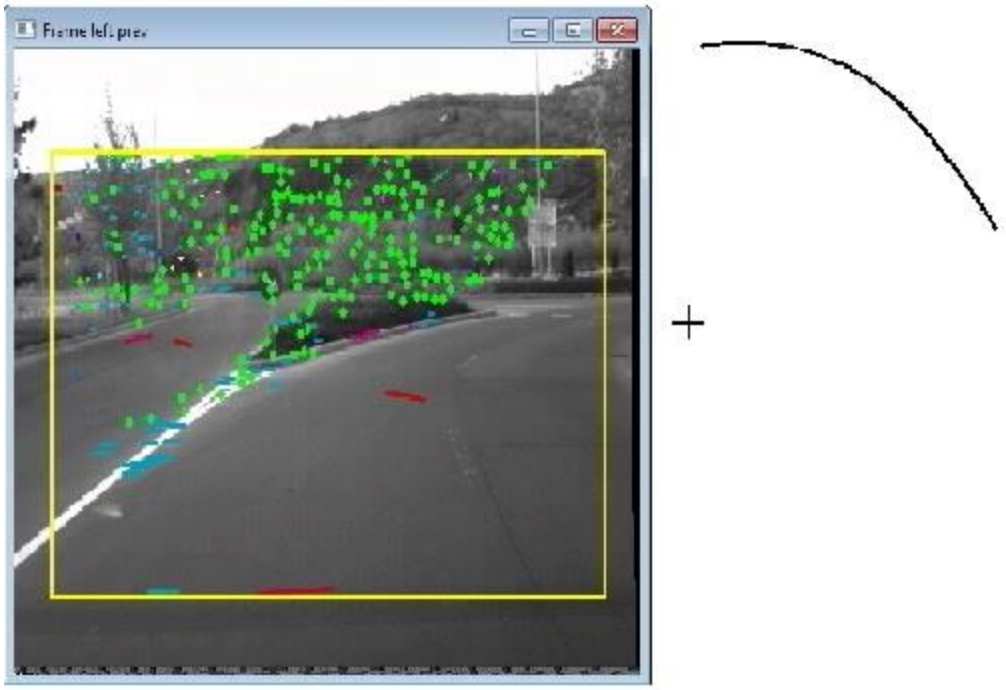


Trajectory for passing 3 times through a roundabout – top view

- PERSENS (Sensorial Perception, Modeling and Representation of the World Model for Driving Assistance Systems, National Project)

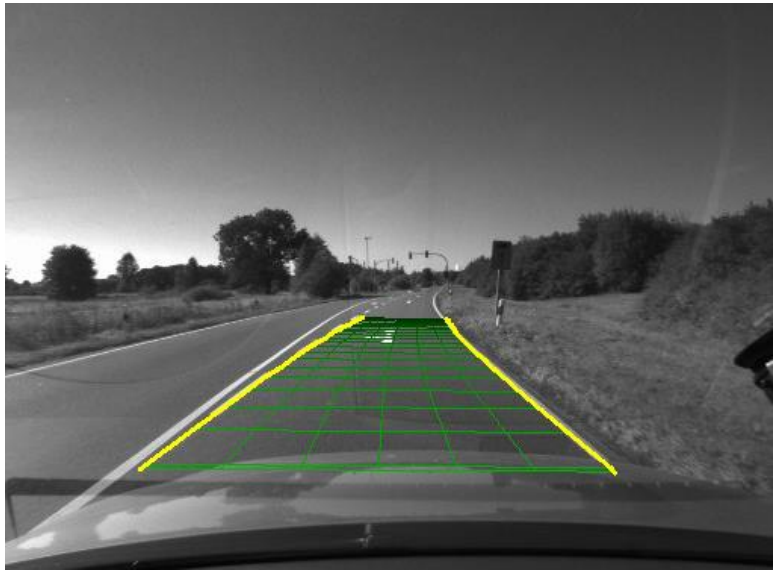


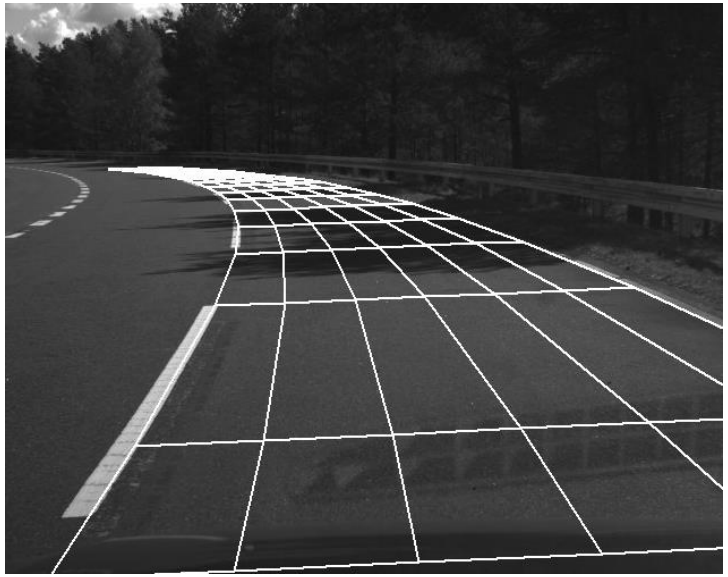
Vision based ego-motion estimation using a stereo system



Lane detection and tracking

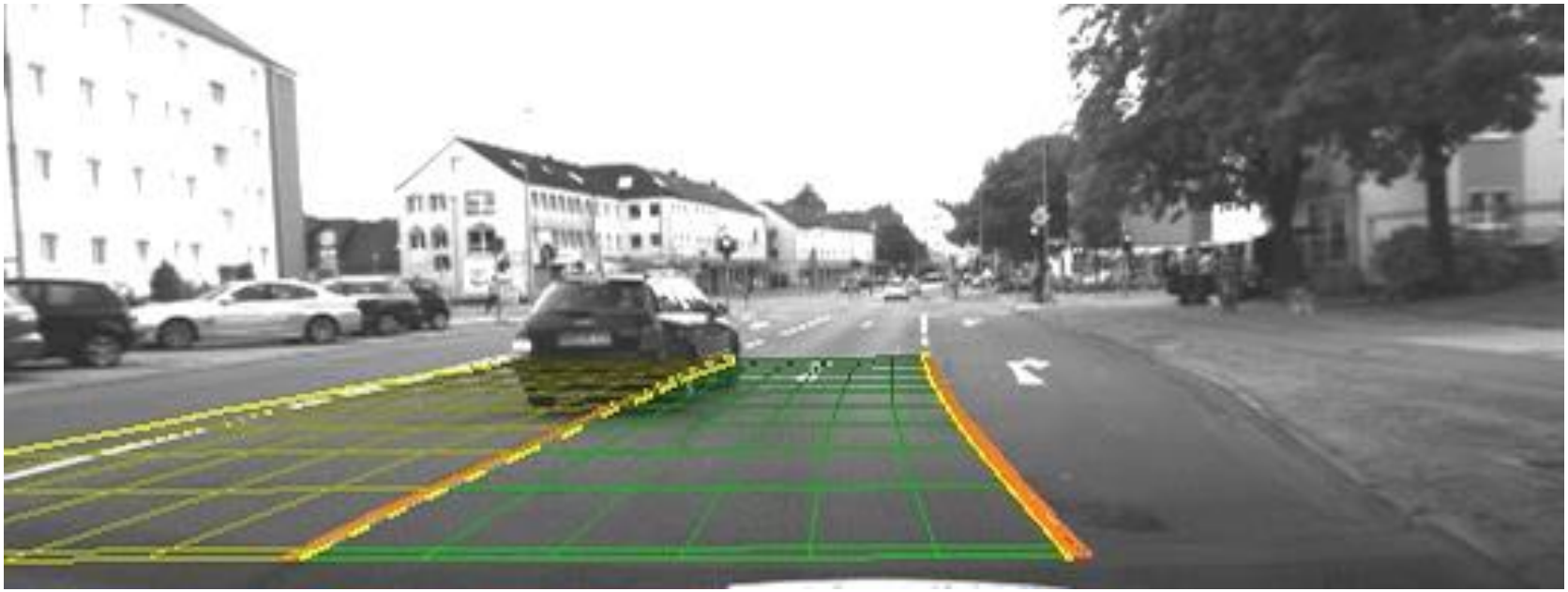
- Lane modeling using 3D clothoids
- Extraction of lane delimiting features by combining stereo and grayscale image information
- Lane model parameter fitting using Kalman filters and particle filters
- Suitable for marked and unmarked, highway and urban roads





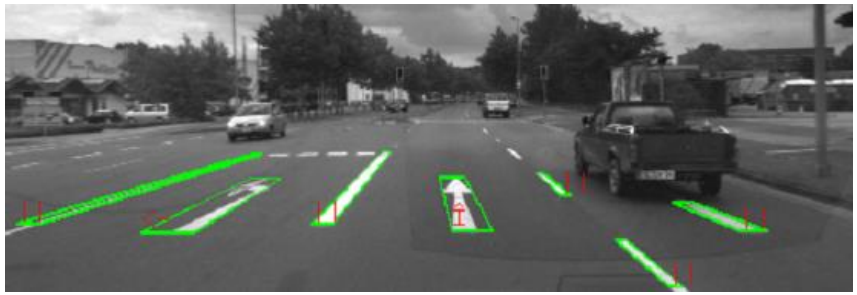
- SCABOR (Stereo Camera-Based Object Recognition, industrial project with Volkswagen AG)
- DESBOR (Dense Stereo Camera-Based Object Recognition, industrial project with Volkswagen AG)

Lane detection and tracking



Detection, 3D localization and classification of painted road objects

- Extraction and 3D localization of painted features from grayscale images, using stereo 3D information to select only road edges
- Classification of the painted road objects into lane delimiters and arrows
- Recognition of arrow types

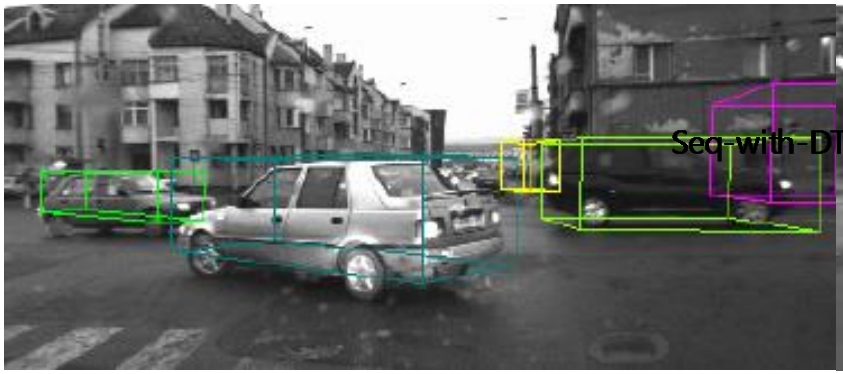


- INTERSAFE-2 (Cooperative Intersection Safety 2, FP7 Project)

Detection, 3D localization and classification of painted road objects

Obstacle detection and tracking

- Perceptual grouping of 3D features
- Integration of 3D and motion information
- Handling the stereovision uncertainties and variable density of features
- Modeling of obstacles as 3D dynamic cuboids having position, size, orientation and speed
- Kalman filter and particle filter based tracking solutions



- SCABOR (Stereo Camera-Based Object Recognition, industrial project with Volkswagen AG)
- DESBOR (Dense Stereo Camera-Based Object Recognition, industrial project with Volkswagen AG)
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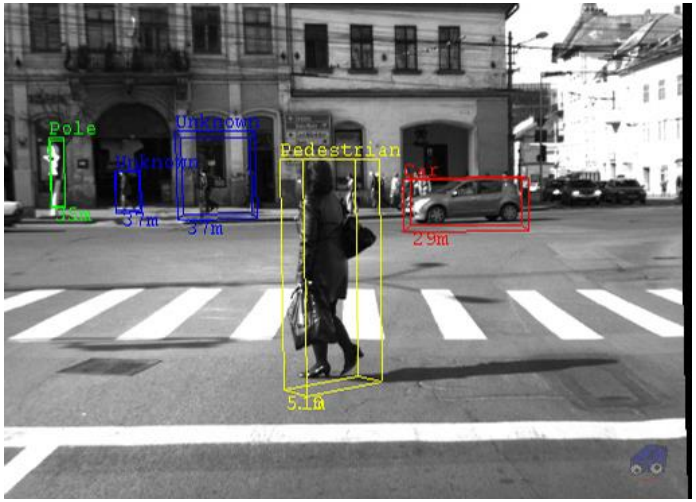
Obstacle detection and tracking

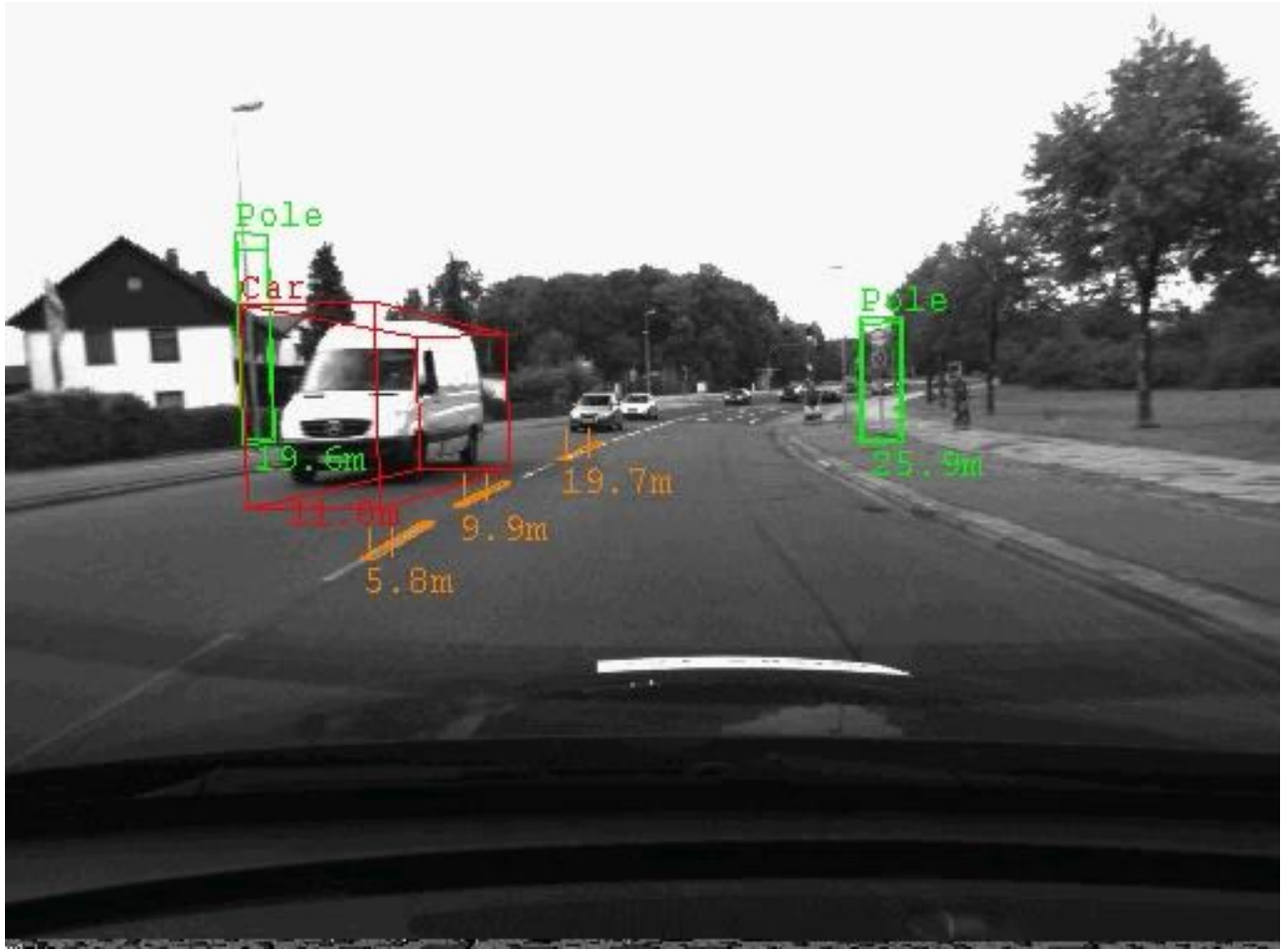
Obstacle classification

- Relevant discrimination features are computed for detected objects, based on 3D information, grayscale image features, optical flow and 3D motion
- Classifiers are trained using a large database of examples
- Real-time classification in real traffic scenarios

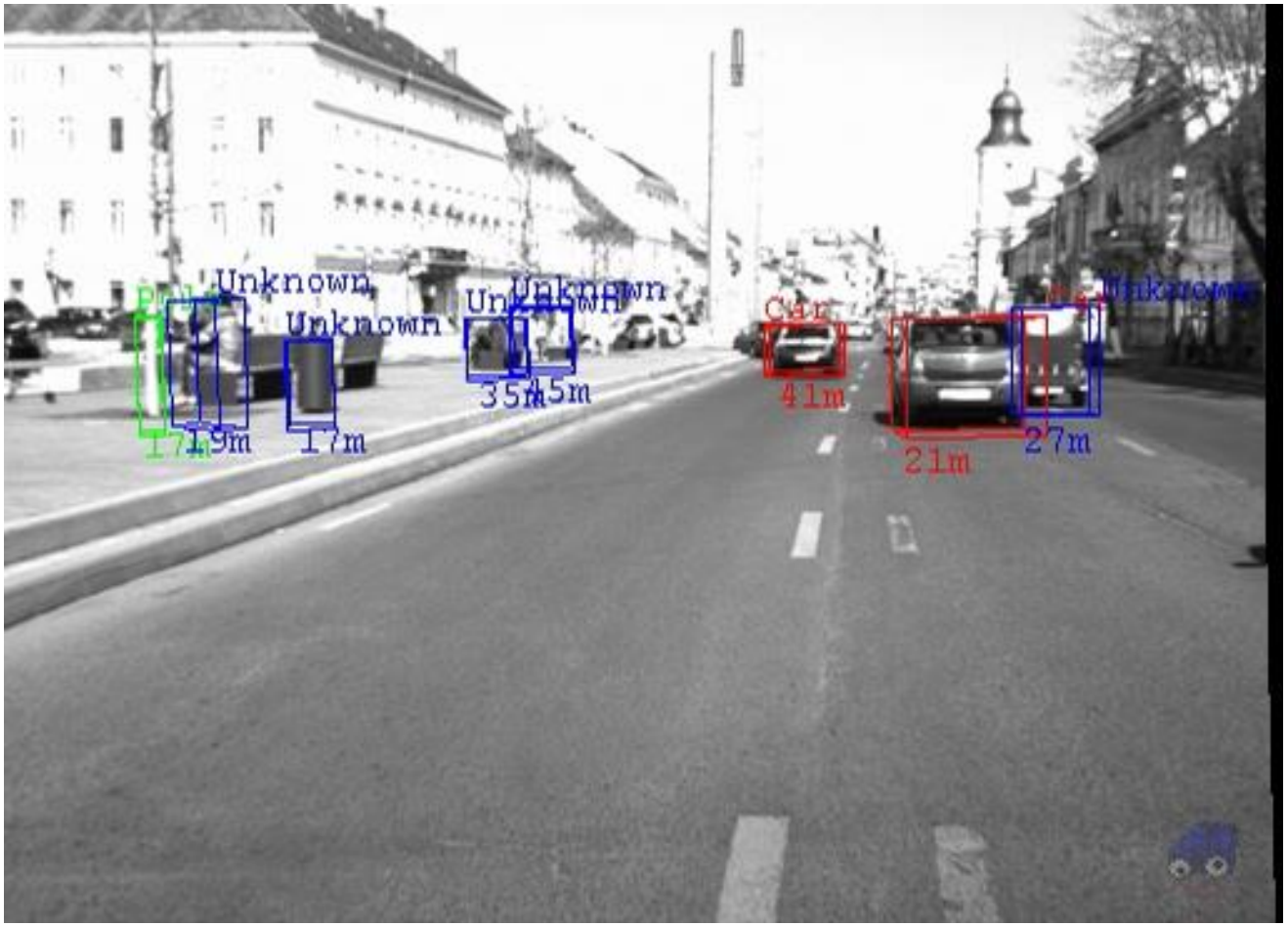


- DESBOR (Dense Stereo Camera-Based Object Recognition, industrial project with Volkswagen AG)
- DESPED (Dense Stereo Camera-Based Pedestrian Detection, industrial project with Volkswagen AG)
- INTERSAFE-2 (Cooperative Intersection Safety 2, FP7 Project)
- PERSENS (Sensorial Perception, Modeling and Representation of the World Model for Driving Assistance Systems, National Project)

Obstacle classification

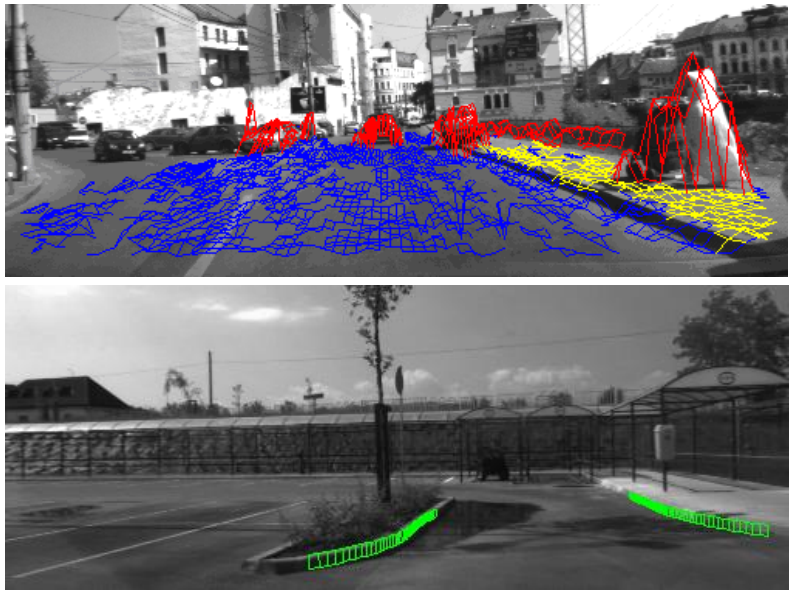


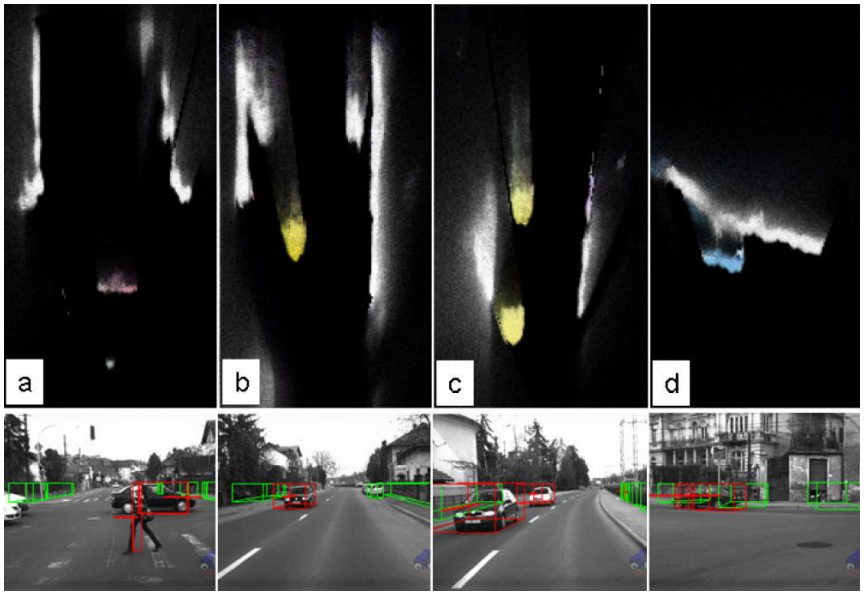
Obstacle classification



Perception and representation of unstructured environments

- Dense stereo 3D information is used to build digital elevation maps
- Elevation map cells are classified into road, obstacle or intermediate
- Dynamic occupancy grids are used for tracking the occupied cells
- Curbs and sidewalks can be extracted from elevation map processing





- DESBOR (Dense Stereo Camera-Based Object Recognition, industrial project with Volkswagen AG)
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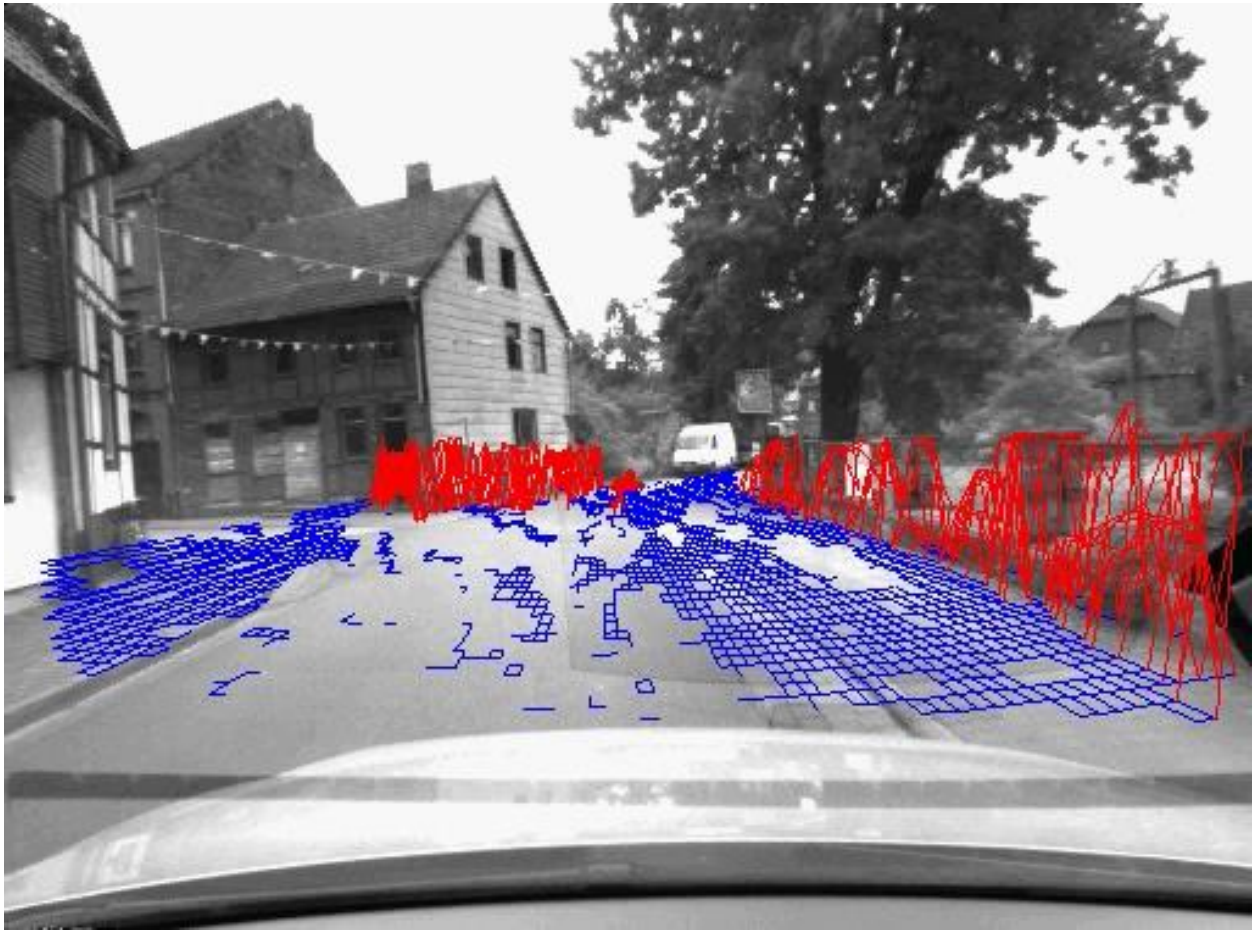
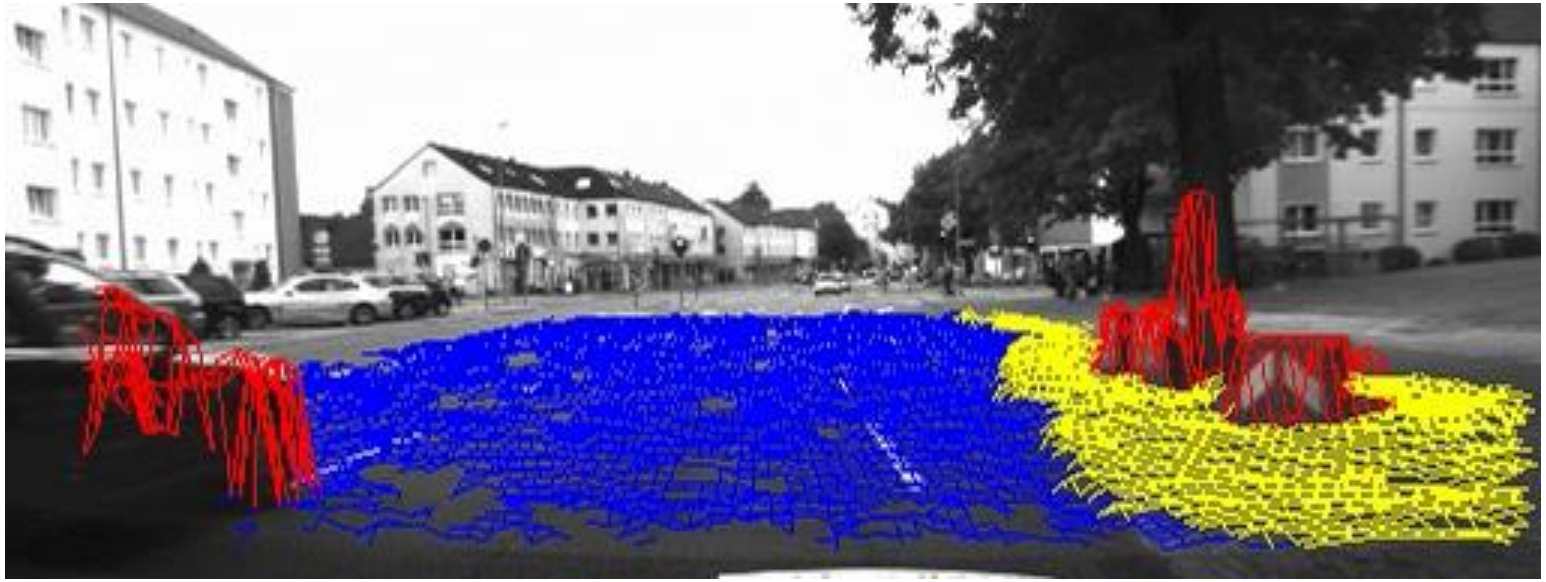
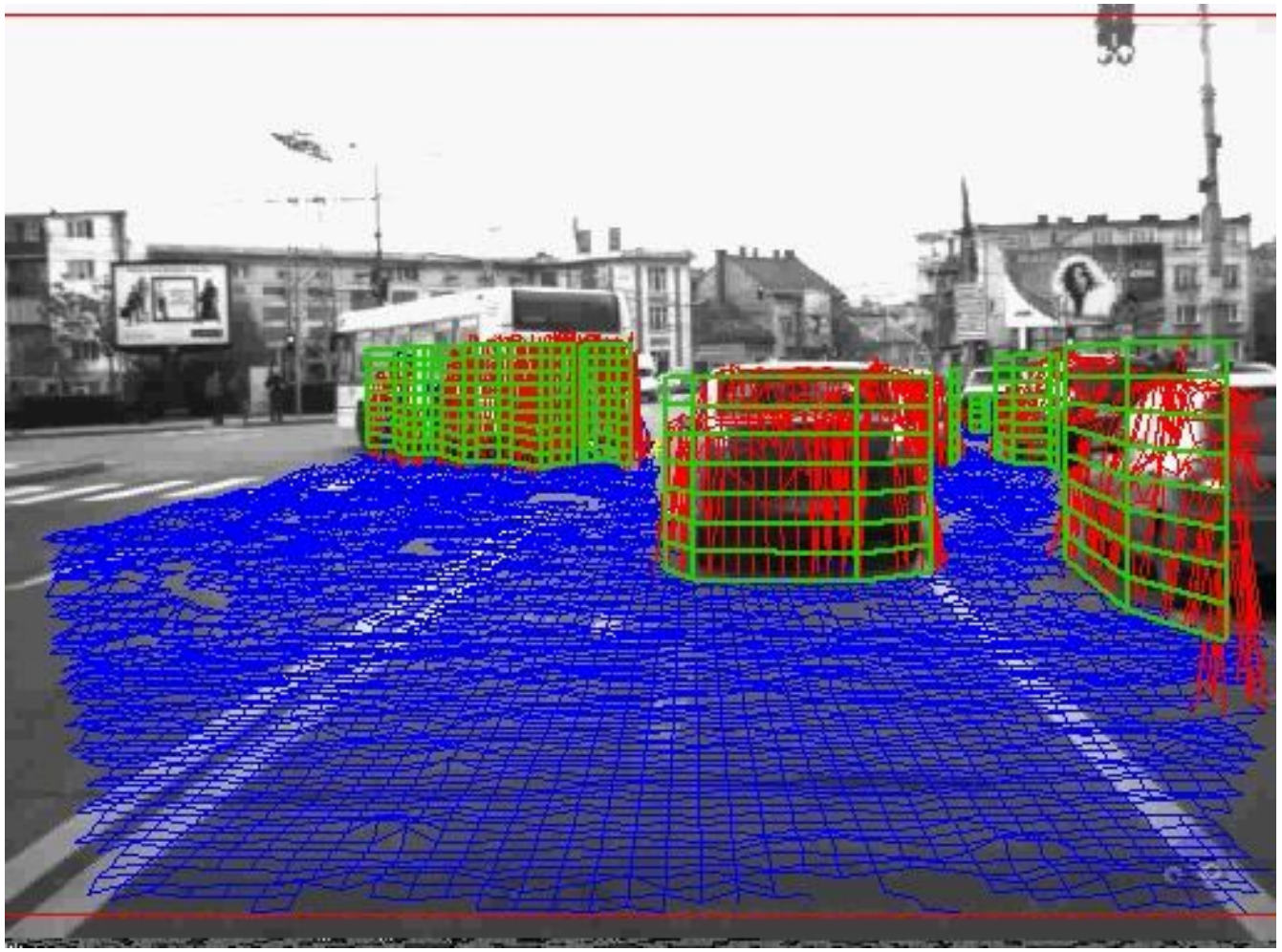
Perception and representation of unstructured environments



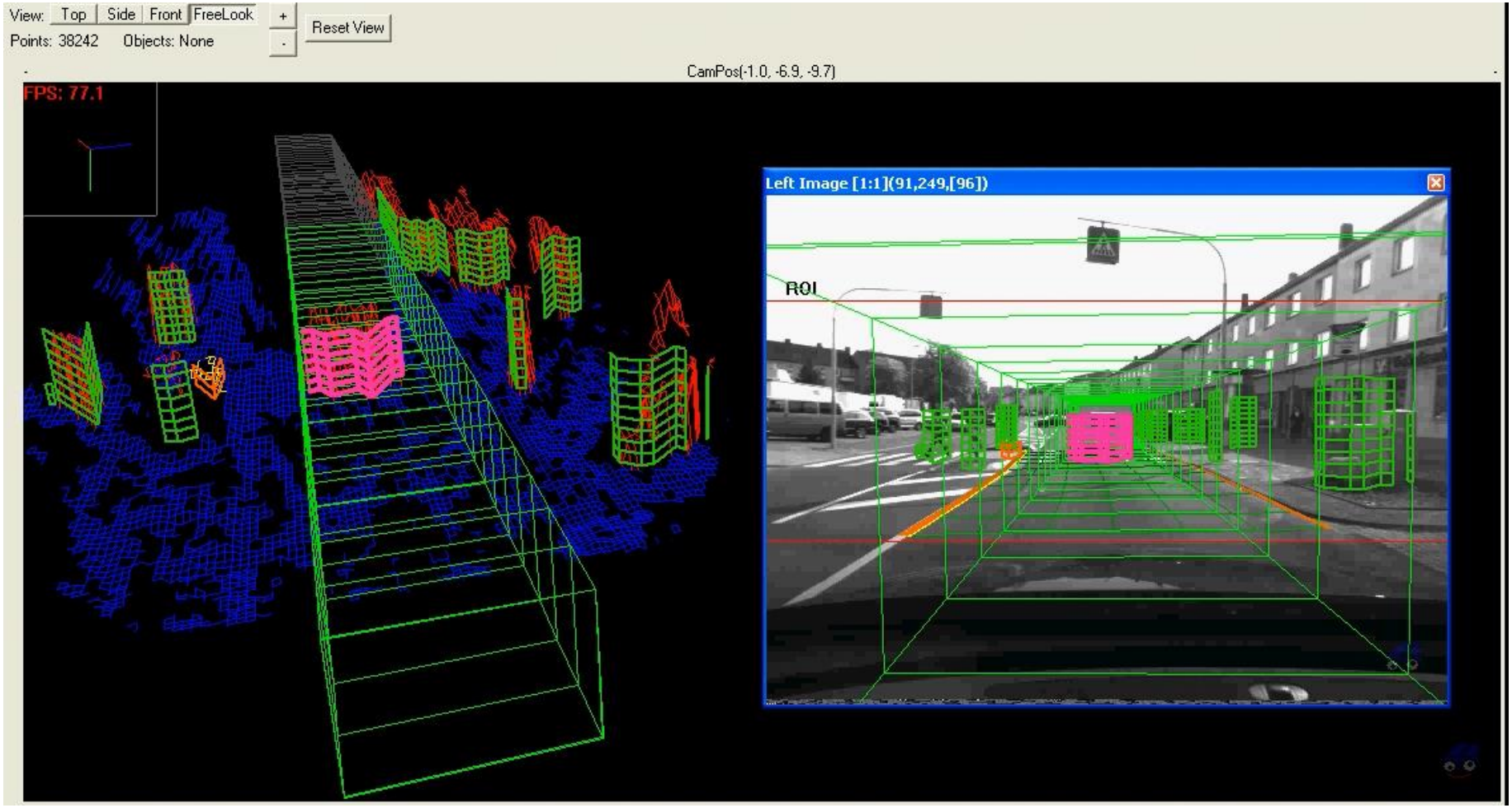
Perception and representation of unstructured environments



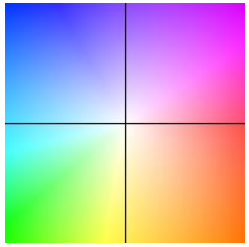
Polyline based delimiters



Forward collision detection



Dynamic Environment Modeling
Motion Estimation Based on ICP Technique



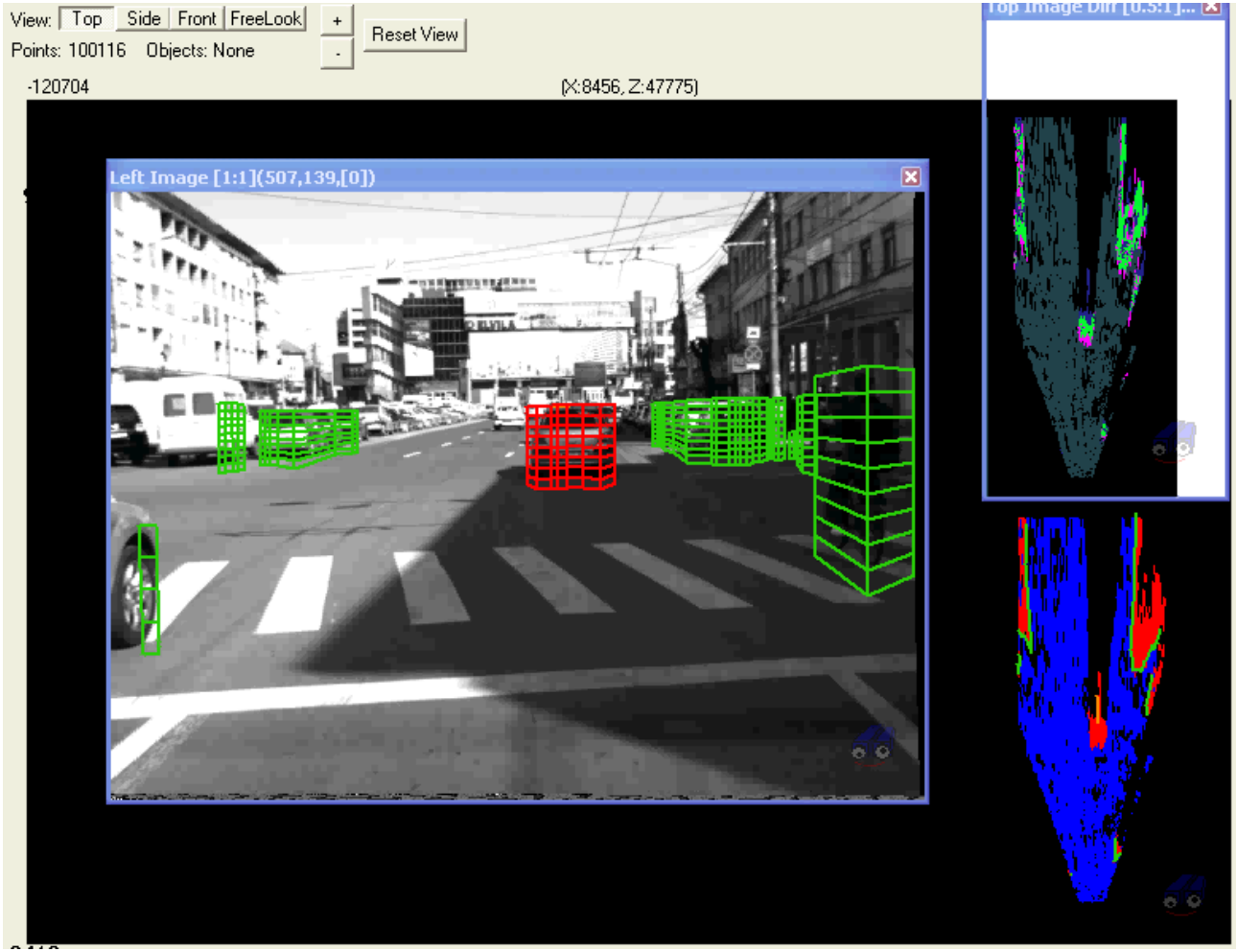
Color Encoding of Object Speeds

Hue: Orientation
Saturation: Magnitude

Dynamic Environment Modeling
Motion Estimation Based on Map Differences

Static Objects:
Green

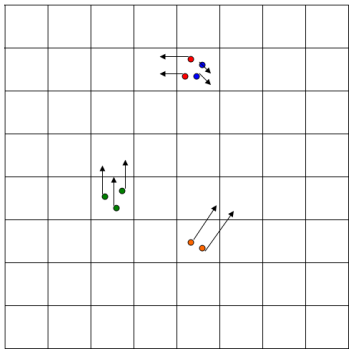
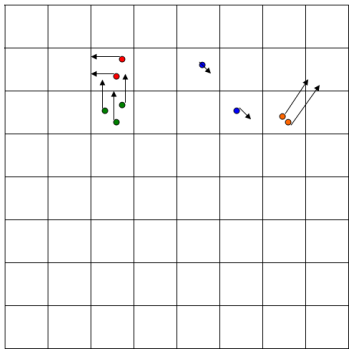
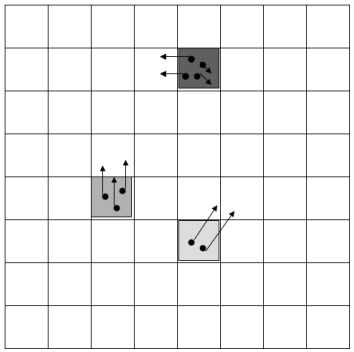
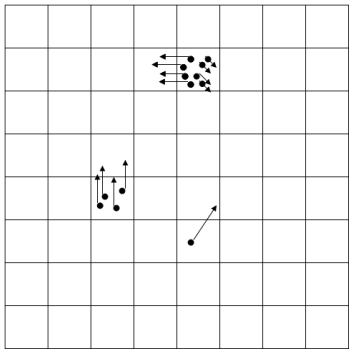
Dynamic Objects:
Red



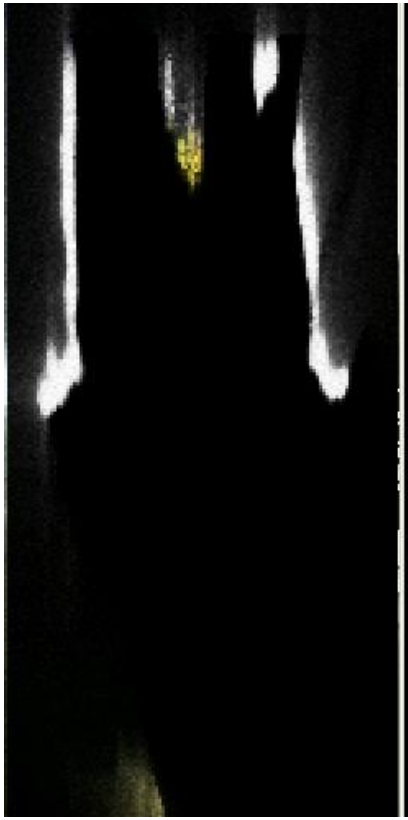
Dynamic Objects: Object Speed > 15km/h

Dynamic Occupancy Grid Tracking

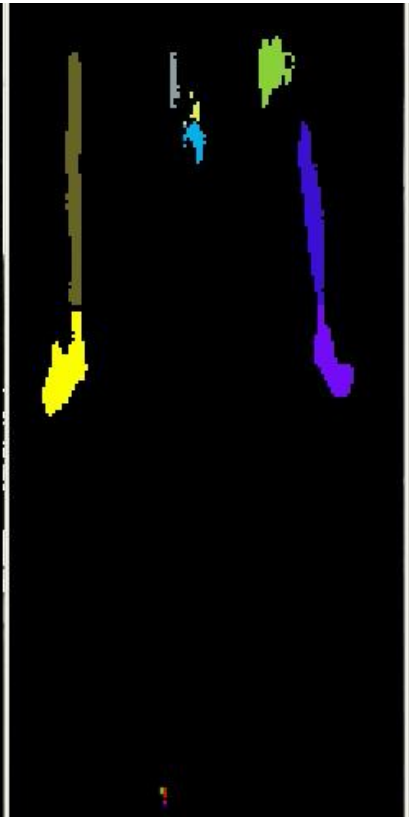
- **Particle-based occupancy grid tracking**
  - **Based on dense stereo results**
    - Raw 3D data is converted into an instantaneous elevation map
    - Obstacle areas identified in the elevation map are used for grid updating
  - **Dynamic occupancy is encoded by particles**
    - Occupancy probability is given by the number of particles in a cell
    - Each particle has speed and orientation, thus the particle population in a grid cell also encodes a speed probability distribution
    - Tracking becomes the process of moving particles from one cell to another, multiplying or deleting them based on measurement data
  - **The dynamic grid can be used for 3D object extraction**
    - Cells are grouped together based on their neighborhood and common speed
    - The resulted object receives speed and orientation without need of object-level tracking

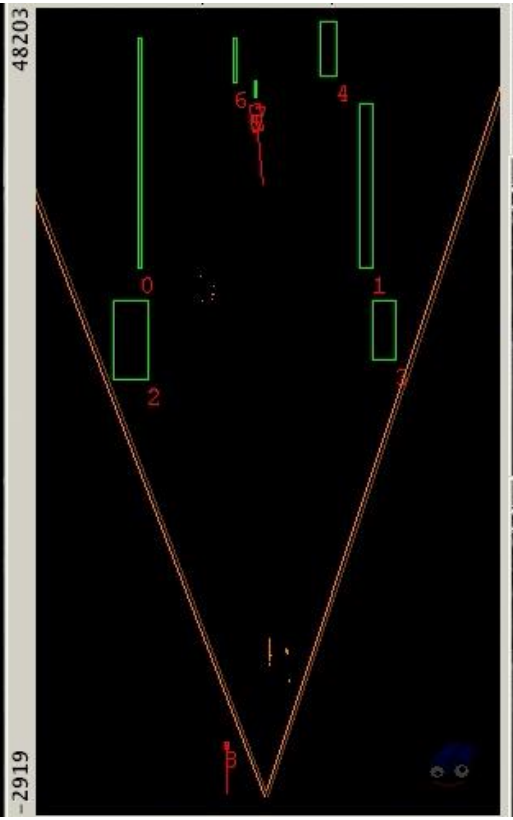
Dynamic Occupancy Grid Tracking



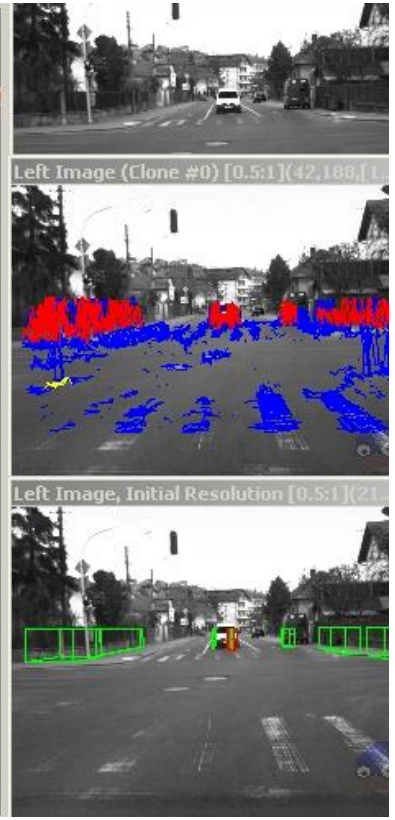
Dynamic Occupancy Grid



Grid labeling

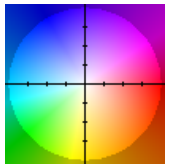


3D Objects: top view



3D Objects: perspective

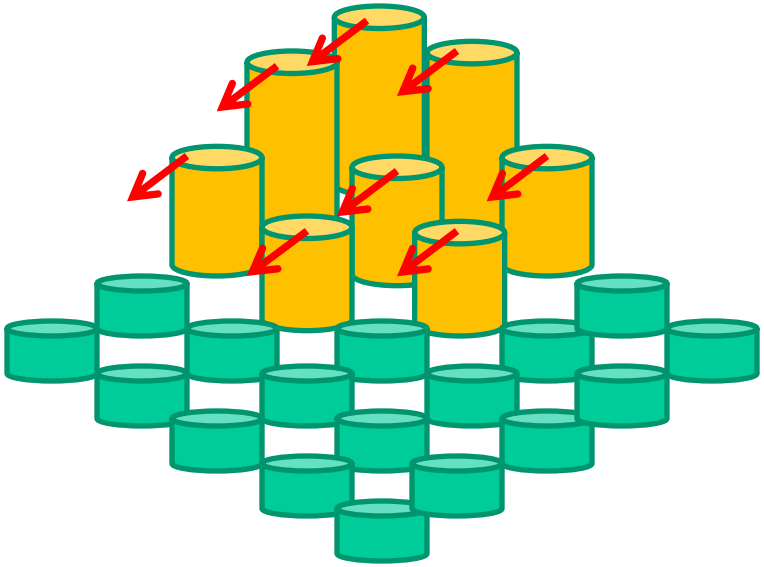
Color encoding

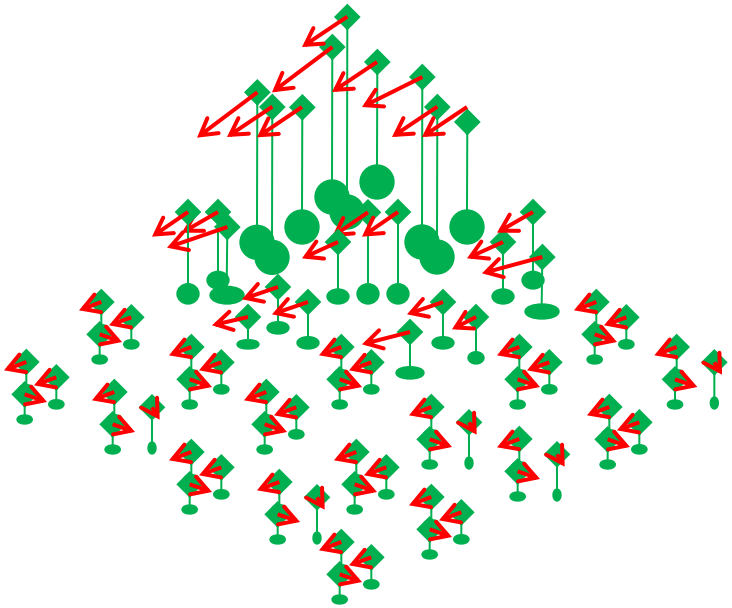


R. Danescu, F. Oniga, S. Nedevschi, “Modeling and Tracking the Driving Environment with a Particle Based Occupancy Grid”, IEEE Transactions on Intelligent Transportation Systems, vol. 12, No. 4, December 2012, pp. 1331-1342.

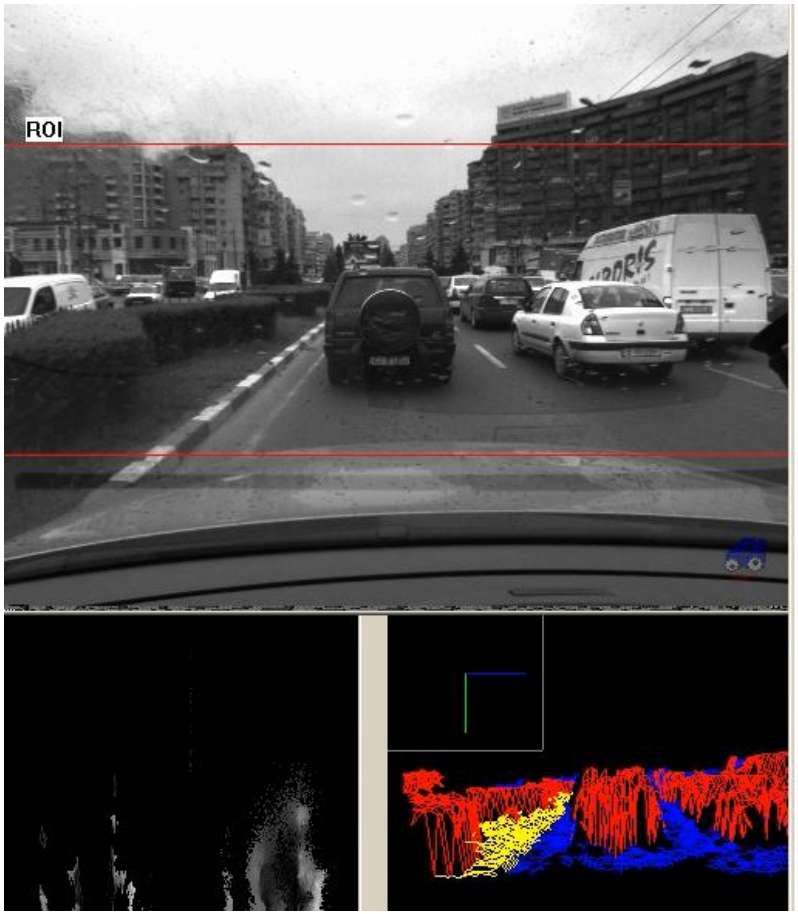
Dynamic Elevation Map Tracking

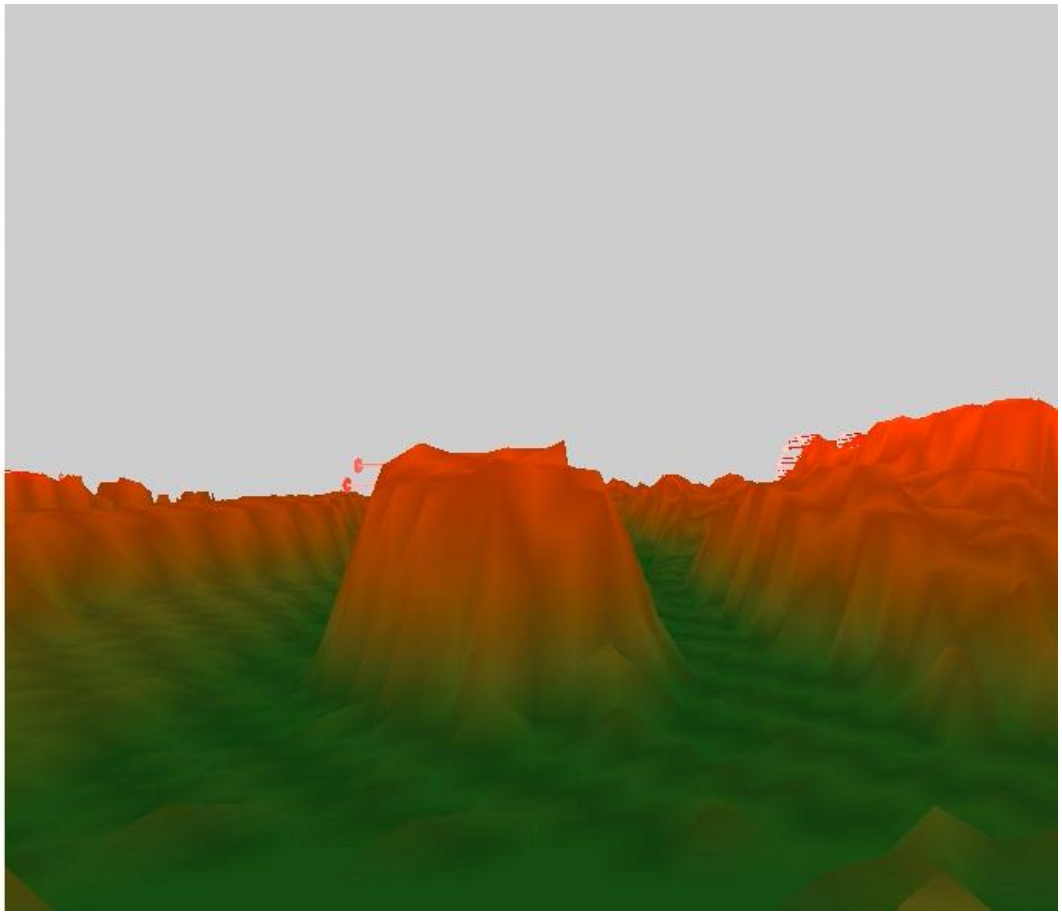
- **Extension of the Particle Occupancy Grid and of the Elevation Map**
  - **A population of particles is present in each grid cell**
  - **The particle has position, height and speed**
  - **The raw elevation map extracted from dense stereo data is used as measurement – not limited to obstacle areas anymore**
  - **The particle's survival chances depend on how well the particle's height matches the height of the measurement data**





Dynamic Elevation Map Tracking





Raw heights

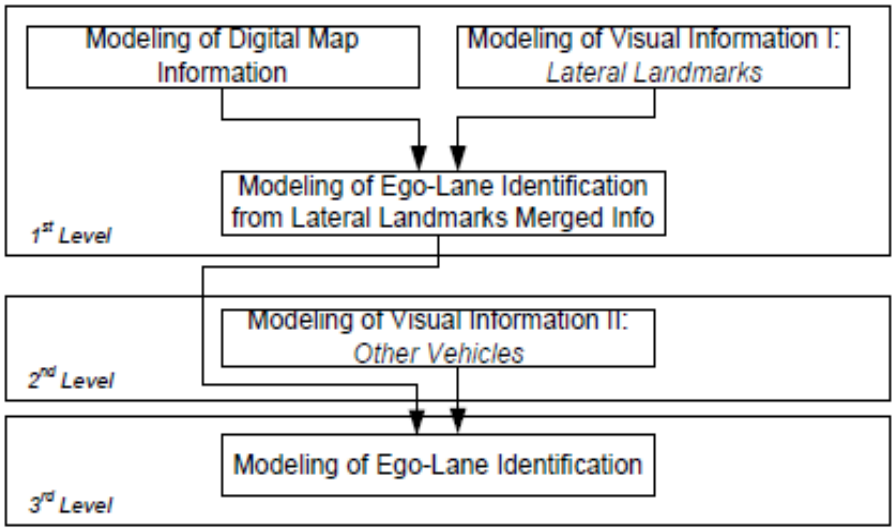
Filtered heights

Raw elevation map - perspective

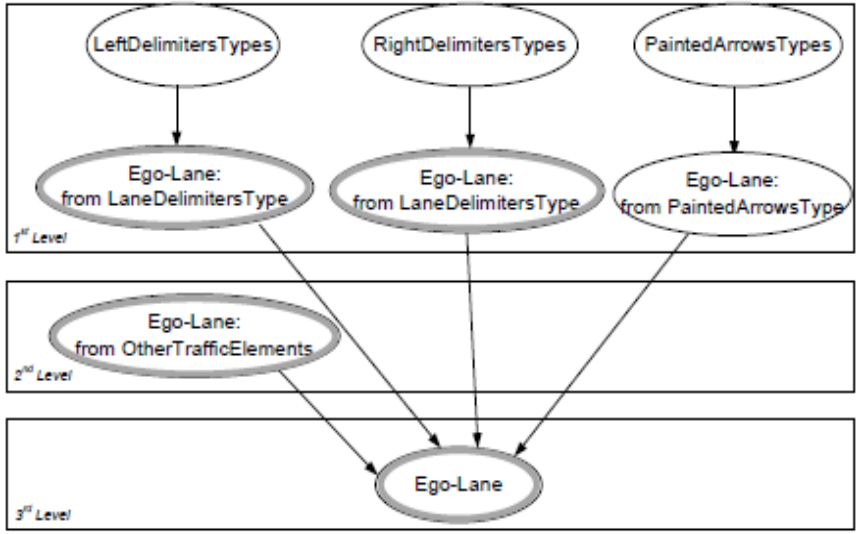
Tracked elevation map, perspective view

High level reasoning on perception and domain knowledge

- **Improved environment perception & scene understanding by reasoning on the sensorial information and domain knowledge (maps, rules)**
- **the sensorial perception is characterized by uncertainties and inaccuracies; the probabilistic methods handle successfully this kind of data, therefore are most suitable approach**
- **the used probabilistic model: Bayesian networks**
- **Achievements: Ego-vehicle current lane identification; Identifying driving situations related to lane change maneuvers; Situation and risk assessment**



Hierarchical description of the proposed solution



The structure of the proposed Bayesian network

- **INTERSAFE-2 (Cooperative Intersection Safety 2, FP7 Project)**

Thank you for your attention