Challenges and opportunities in ADAS: A talk on my thesis

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December 16, 2015

Overview

1. Compilation of recent scientific publications
   - Key resources
   - Compilation of ITSC 2015 and ITS Trans. 2015 papers
   - Summary of topics
2. My research interests
   - Basic considerations
   - Problem formulation
   - Proposed approach
3. State-of-the-art technologies
   - Object detection

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ITS research

ITS Conferences

- 2015 IEEE 18th International Conference on Intelligent Transportation Systems (ITSC 15).
- 2015 IEEE Intelligent Vehicles Symposium (IV 2015).

ITS Journals

- IEEE Transactions on Intelligent Transportation Systems (IF: 2.377)

Related Conferences & Journals

- IEEE Transactions on Pattern Analysis and Machine Intelligence (IF: 5.781)
- 2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR).
- 2015 IEEE International Conference on Robotics and Automation (ICRA).
- 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).

ICRA 2015

Ref.	Sensor(s)	Task	Key concepts
Paz	Color Monoc.	Road segmentation	3D geomet. data, appearance-b'd color segmentation (MAP[1])
Wei	2D LIDAR	Road context inference	Random obs'd vehicle states, probabilistic ap. (GNG[2], GP[3])
Ali	-	Platooning control	CTH[4]
Driggs-C.	Monitoring	Driver behaviour	Realistic data, flexible algorithm
Amanatiadis	Laser+Color	Vehicle 'extraction'	"A-robot-for-a-wheel"
Cunningham.	LIDAR	Decision making	POMDP[5], forward simulation (MPDM[6])
Zhang	Color Monoc.	Traversable reg. detec.	Multi-scale super-pixels, ELM[7], online learning
Maddern	2D LIDAR	Localization	Prior maps, localization cost function, probab. framework

Table : ICRA papers on ITS

[1] Maximum A Posteriori estimation.

[2] Growing Neural Gas.

[3] Gaussian Process.

[4] Constant Time Headway policy.

[5] Partially Observable Markov Decision Process.

[6] Multipolicy decision-making.

[7] Extreme Learning Machine.

Ref.	Sensor(s)	Task	Key concepts
Vatavu	Omnid. stereo	Obstacle det. & track.	Industrial AGVs[8], DEM[9], classification, ICP[10], Kalman filter
Galceran	-	Veh. track. (oclusions)	Ocluded state estimation, dynamics model, hGMM[11], KLD[12]
Verginis	Camera	Platooning	Unicycle vehicles, decentralized kinematic control
Heinrich	-	Trajectory optimization	Rules and heuristics, LQG[13], GPU
Sezer	-	Vehicle interaction	T-junction intersections, intention-aware decision, MOMDP[14]

Table : IROS 2015: WeDT15 Regular session (ITS)

8 Automated Guided Vehicles.

9 Digital Elevation Map.

10 Iterative Closest Point.

11 hybrid Gaussian Mixture Model.

12 Kullback-Leibler Divergence.

13 Linear-Quadratic Gaussian.

14 Mixed Observability Markov Decision Process.

Ref.	Sensor(s)	Task	Key concepts
Quintero(UAH)	Infrared cams	Pedestrian intention	Intentions 1 s ahead, B-GPDM[15], Naïve Bayes classifiers
Schulz(Bosch)	Stereo cam	Pedestrian intention	IMM[16] Filter, head pose estimation, real-time
Wada(JP)	Pressure (sole)	Pedestrian avoid.	Pressure sensors attached to sole of a pedestrian
Chen(CN)	LIDAR	Vehicle tracking	Pose estim., likelihood field model, importance sampling

Table : ITSC 2015: Interaction of Automated Vehicles with other Traffic Participants

[15] Balanced Gaussian Process Dynamical Models

[16] Interacting Multiple Model

ITSC 2015

Ref.	Sensor(s)	Task	Key concepts
Borrmann(DE)	-	Resource management	Heterogeneus embedded platf., fail-operational scheme
Nilsson(Volvo)	-	Automated driving	Long vehicles, driver model, prediction models
Keller(DE)	-	Emergency maneouvers	Traject. planning, predictory ctrl., real-time
Jahangiri(US)	Cameras	Red-light runn. pred.	SVM & RF[17] classif., mRMR[18] feat. selection
Damerow(DE)	-	Behavior planning	FDM[19] interaction-aware prediction, prob. models
Levi(GM)	Rear-view cam	Pedestrian detection	AFS[20], NMS[21] tracking, local-motion features
Stolte(DE)	Cam, radar,...	Automated driving	Protective vehicle for highway road works
Ward(SE)	Infrast. cam	Driver intention	Intersections, k-NN, RF, SVM
Scanlon(Toyota)	EDRs[22]	Driver behavior	Pre-crash acceleration profile model at intersections
Westerhoff(DE)	Camera	Camera control	Parameter selection, image quality
Nilsson(SE)	-	Maneuver intention	Simple logic rules, lane change maneuvers
Söntges(DE)	-	Evasive trajectories	Upper bound of solution, reports if no solution exists
Guo(Toyota)	Stereo cam	Id. leader vehicle	Vehicles detect., lane assignm., ctrl. based on leader
Tian(KIT)	Grey cam.	Cyclist detection	Cascaded classifiers, shared features, geometric constr.
Romera(UAH)	Phone cam	Vehicle det. & track.	Multi-scale, simple geometric constr., vanishing point

Table : ITSC 2015: Advanced Vehicle Safety Systems (I-IV)

[17] Random Forests

[18] minimum Redundacy Maximum Relevance

[19] Foresighted Driver Model

[20] Accelerated Feature Synthesis

[21] Non-maximal suppression

[22] Event Data Recorders

ITSC 2015

Ref.	Sensor(s)	Task	Key concepts
Stellet(Bosch)	CAN, laser	Vehicle motion pred.	EM[23] Gaussian process noise at longitudinal predict.
Hashimoto(JP)	Grey cams	Pedestrian behavior	Turning vehicle, DBN[24] context integrat., particle filter
Janardh.(Volvo)	Radar, cam	Collision avoidance	Rigid trucks, steering within lane, PD controller
Durai.(Daimler)	Rad+las+stereo	Data association	T2TA[25], likelihood-ratio tests, non-kinematic inform.
Koesdw.(CA)	Press., Kinect	Driver inattention	(S-)PCA[26] dimen. red., RF class., PSO[27] multi-view cl.
Kang(KR)	GPS	Vehicle localiz.	GPS under failure of vision, clothoidal constraints
Jiang(FR)	Posit., inertial	Vehicle dynamics	Low-cost, roll-pitch dynamics, RLS[28], Kalman filters
Eggert(Honda)	-	Lane-change behav.	Trajectory alternatives, "Foresighted Driver Model"
Nishino(JP)	Camera, CAN	Markings deteriorat.	Projection transform, GIS, stripping ratio distribution
Li(CH)	Cameras, CAN	Maneuvers transition	Highways, driving data, transition probabilistic model
Herrmann(TUM)	Braking+steer.	Criticality classificat.	Evasion, MinMax optimal ctrl., RF class. with feat. sel.
Horgan(Valeo)	-	ADAS survey	Vision-based ADAS, taxonomy
Sieber(DE)	-	Emergency steering	Distracted driver, human-machine interaction
Monteil(IE)	Trajectory data	Driver behaviour	IDM[29] car-following model, EKF, real-time

Table : ITSC 2015: Advanced Vehicle Safety Systems (V-VIII)

[23] Expectation Maximization

[24] Dynamic Bayesian Network

[25] Track-to-track association

[26] (Supervised) PCA

[27] Particle Swarm Optimization

[28] Recursive Least Squares

[29] Intelligent Driver Model

ITSC 2015

Ref.	Sensor(s)	Task	Key concepts
Chen(TW)	Color cam	Rear light status	Symmetrical SURF, rear lamp response func., no thresh.
Takeuchi(JP)	3D LIDAR+maps	Blind area predict.	Residential areas, lane network info., particle filter
Köhler(DE)	Stereo cam	Pedestrian intention	Motion contour HoG descr., silhouettes, L-SVM
Fang(FR)	Color+LIDAR	Object tracking	Small region from pix., bidirectional region growth in las.
Gonçalves(TUM)	Eye+Kinect	Driver state	Emergency take over request, collision probability
Rajaram(US)	Color cam	Pedestrian detect.	Analysis of state-of-the-art, strengths and limitations
Philipsen(DK)	Color cam	Traffic light rec.	Database, learning-based detect., integral channel feat.

Table : ITSC 2015: Advanced Vehicle Safety Systems (VIII-IX)

ITSC 2015

Ref.	Sensor(s)	Task	Key concepts
Rapp(DE)	Short rg. radars	Localization	Urban, Monte-Carlo, grid-based Markov chain, Lvy process
Raaijma.(Audi)	Camera	Roundabouts	Roundab. geometry model, a priori map
Fernánd.(UAH)	Stereo cam	Road detection	Decision trees class., 2D(texture,...)+3D(normals,...) featur.
Rieken(DE)	LIDAR	Environ. model	Perception-driven, lane detect., grid-based repres., tracking
Driggs(US)	-	Driver intent	High level goals, labelled dataset of lane changes, classif.
Gan(CN)	Color cam	Pre. vehicle det.	4-dim mapping of colors, corners/edges feat., SVM, PSO
Noh(KR)	LIDAR+pose	Situation assesm.	High-level fusion, prob. situation ass., local dynamic map
Savastürk	IR+stereo	Vehicle detect.	Comparison study, stereo + mono IR sensor combination
Bender(AU)	GPS+IMU+CAN	Driver intent	Intersections, predicting manoeuvres, QDA[30], driving data
Seeger(BMW)	Stereo+LIDAR	Grid mapping	Multiple hypoth., evidential grid map., neighboring cells
Kumar(US)	Grayscale cam	Speed lim. sign	Real-time, shape & intensity,task MSERs[31], Kalman f., NN[32]
Bisoffi(IT)	CAN	Driver intention	Desired long. *jerk* (deriv. of accel.), Kalman f., scaling tec.
Rus(RO)	Stereo	Pedestrian rec.	Intensity, depth and flow feat., modality pertinence, L-SVM
Nguyen(VAG)	Cam+LIDAR	Markers detec.	Detection, Kalman f., GMM, RANSAC road boundary est.,
Liu(GE)	Driver cam	Face detection	Eyes occluded by shadow, driver intention, robust algorit.
Kopinski(GE)	ToF	Hand gesture rec.	Depth data, MLPs[33], PCA, dynamic hand gestures
Costea(RO)	Phone cam	Pedestrian detec.	Real-time, channel feat. based multiscale detect. scheme
Ramyar(US)	GPS+CAN	Driver behaviour	Intersect., Takagi-Sugeno fuzzy models, Gath-Geva cluster.

Table : ITSC 2015: Driver Assistance Systems

30 Quadratic Discriminant Analysis

31 Maximally Stable Extremal Regions

32 Neural Network

33 MultiLayer Perceptrons

Ref.	Sensor(s)	Task	Key concepts
Vasic(FR)	LIDAR, GPS	Multi-obj. track.	GM-PHD[34] filt., detect-bef.-track, rect. shape, GCI[35] fusion
Zhang(CN)	3D LIDAR	Road bound. det.	Double layer beam model, intersection shape recog., UGV
Kehl(Daimler)	Stereo cam	Road sign detect.	HSL color segment., 3D sign geometry, temp. integration
Rapp(DE)	Short rg. radars	Grid map	Group-wise grid map registration, graph-based approach
Nilsson(DA)	LIDAR+cam...	Track fusion	Correlated inputs, comparison, state estimation accuracy
Belaroussi(FR)	Cam, map	Fog model	Estimating visibility cond. from traffic sign information
Asvadi(PT)	Laser, pose	Object det&track.	2.5D grid/map, object-level represent., data ass. & Kalman f.
Wenzel(Bosch)	Phone cam	Addit. traffic sign	Comparison, MSER-based approach[36], database
Karaimer(TR)	Omnid. cam	Vehicle classif.	Shape/gradient-based class., kNN, HOG, SVM, vehicle types
Xie(BMW)	Multi-laser	Calibration	Online extrinsic cal., planar checkerboard, noise, real-time
Drage(AU)	LIDAR	Road edge detec.	Multi-layer LIDAR, orientation and position measurem.
Vitor(BR)	Stereo cam	Semantic info.	Semantic ctxt., evidential grids, Texton/Dipston maps, boost
Schmidt(Audi)	Two cams	Lane bound. det.	3D model as consecutive linear segments, error model
Rummel.(FR)	LIDAR, CAN	Occupancy grid	Conditional Monte Carlo dense occupancy tracker
Smart(CA)	Stereo cam	Marking detect.	Bird's Eye view, filtering bef. IPM[37], semi-supervised learning
Dierkes(DE)	-	Road representat.	Uncertainty repres., multiple hypothesis, repres. language

Table : ITSC 2015: Sensing, Vision and Perception

[34] Gaussian Mixture Probability Hypothesis Density

[35] Generalized Covariance Intersection

[36] Maximally Stable Extremal Regions

[37] Inverse Perspective Mapping

Ref.	Sensor(s)	Task	Key concepts
Kataoka(JP)	Camera	Pedestrian intent.	Pedestrian activities class., DT[38] recog., detection-based ROI
Shreve(Xerox)	Color cam	Static occlusion	Location of static occlusions to help well-known tracking alg.
Yalla(Toyota)	Color cam.	Ease of driving	Classification by Holistic Anal. of Scene Envir., machine learning
Sanberg(NL)	Stereo cam	Free-space segm.	Color-only stixel segment., real-time, based on slower disparity seg.
Xu(Xerox)	Infras. cams	HOV[39] lane	Overhead gantries or roadsile poles, front & rear seats, fusion
Van Gastel(NL)	Infras. cam	Pedestrian track.	Crowded scenes, occlusion handling, changes in motion pattern
Woudsma(NL)	Pano cam	Road mark. map	Learning, IPM, segmentation, MRF[40] probab., traffic situations
Cui(CN)	Color cam	Taillights detect.	Daytime, veh. detec., candidates clustering, rear-light state

Table : ITSC 2015 Special Sessions: Computer V. and Imaging Sys. in Transportation

[38] Dense Trajectories

[39] High Occupancy Vehicle

[40] Markov Random Field

Ref.	Sensor(s)	Task	Key concepts
Di(CN)	Color cam	Road scene parsing	Nonparametric, spatial prior, previously observed histograms
Kawan.(JP)	Color cam	Pedestrian re-detec.	Distant pedestr., detec. from other vehicles, prior knowledge
Kellner(Audi)	Stereo cam.	Curb detec.	Position & orientation invariant, grid map, 3D polygonal chains
Fern.(UEM)	Color+laser	Urban hotspots	On-board perception, pre-collision system, event data recorder
Premebi.(PT)	LIDAR	Env. modelling	Pc.[41] sampling, spatial interp., polar-grid repres., Kriging pred.
Delp(Toyota)	LIDAR	Object clas.&track.	Path planning, bicycles, real-time, anytime algorithm

Table : ITSC 2015 Special Sessions: Envir. Perception for Automated On-road Veh.

[41] Point Cloud

Ref.	Sensor(s)	Task	Key concepts
Aeber.(BMW)	Various	Object class.	Type of an object, high-level fusion, Dempster-Shafer evidence th.
Fu(CN)	LIDAR+Cam...	Path planning	Decision making for autonom. veh., GIS, structured road models
Jian(CN)	LIDAR, pose	SLAM	FastSLAM, STSRCDKF[42], prop. distribution of the particle filter
Klingel.(DE)	GPS, CAN	Traject. predic.	Intersect., context info., 5 s into future, probab. multiclass class.
Ulbrich(DE)	Various	Behavior plan.	Assesment for lane changes, dyn. Bayesian net., unscented var. tf.
Kohl.(DE)	-	Maneuver plan.	Undest. of complex sit., behaviour gener., semantic scene model.
Wang(CN)	LIDAR	Semantic label.	Using pc. to label obj., Voxel-Neighbor Struc., RF clas., CRF[43]

Table : ITSC 2015: Automated Vehicle Operation, Motion Plan. and Navigation

42 Strong Tracking Square Root Central Difference Kalman filter

43 Conditional Random Fields

ITSC 2015

Ref.	Sensor(s)	Task	Key concepts
Iandola(US)	Color cam	HOG Computat.	Energy/time-efficient HOG, reduced precision, SIMD parallelism
Neum.(BMW)	Stereo cam	Free space detec.	Confidence estimation, semi-automatic ground truth
Kim(KR)	-	Bicy. collision av.	Intersection/longitudinal collision, wireless access, simulation
Nguyen(Valeo)	Fisheye cam	Moving-static sep.	Optical-flow based 3D reconstr., moving object detect., efficient
Barn.(Hitachi)	Camera	Vehicle behavior	Uneven road surface detec., motion patterns, HMM class. model
Poggenh.(DE)	Stereo cam	Road markings	Charact., arrows, lines, crossings, histogram of width, OCR, ANN
Cara(NL)	Laser	Car-cyclist scen.	Safety-critical car-cyclist scenarios class., machine learning
Völz(Bosch)	LIDAR	Pedestr. behav.	Beh. of pedestrians at crosswalks, model, features, relevance det.

Table : ITSC 2015: Various sessions

ITS Transactions 2015

Ref.	Sensor(s)	Task	Key concepts
Satzoda(US)	Multiple	Drive analysis	NDSs[44], data reduction, extracting semantic info., lane semantics
Nanxi.(US)	Cam+CAN...	Driver distract.	Drivers' behav. with visual/cognit. distractions , feat., binary clas.
Higgs(US)	CAN+rad+...	Driver behavior	Link driv. states to driv. actions, seg.&clus. of driving beh.
Gahroo.(US)	Trajectories	Inters. phases	Baum-Welch/Bayesian learning, Dirichlet prior, Viterbi inference
Wang(US)	EEG[45]	Driver distraction	Predict distraction (map viewing) using brain activity
Hong(US)	Accel., gyro.	Inertial par. est.	Four-wheel nonlinear vehicle, roll dynam., dual unscented Kalman f.
Guan(CA)	Laser	Road features	Road curbs from a set of profiles, road markings, cracks
Laftc.(US)	IMU	Localization	Loc. using terrain data, lineal dyn. model encoding, bank of models
Qiao(CN)	GPS	Trajectory pred.	Hidden Markov model-based Trajectory Prediction, parameter selec.
Gallen(FR)	Grey cam	Night fog	Night visibility index, presence of night fog, correlation idx., halos
Qu(CN)	CAN, gyro.	Driver model	SMPC[46], driver steering skills, mimic driver's perception
Töpfer(VAG)	Camera	Scene underst.	Estimation of topolog., hierarchical model, nonparam. belief prop.
Attal(FR)	Acc., gyro.	Riding pattern	Machine-learning, database, GMM, HMM
Vatavu(RO)	Stereo cam	Object track.	Crowded env., occ. grid, free-from object delimiters, particle f.

Table : ITS Trans. vol. 16, num. 1

[44] Naturalistic Driving Studies

[45] Electroencephalographic signals

[46] Stochastic Model Predictive Control

ITS Transactions 2015

Ref.	Sensor(s)	Task	Key concepts
Salmane(FR)	Infras. cam	Level crossings	Smart video surveillance, tracking, HMM, Dempster-Shafer
Kim(SG)	LIDAR, cam	Cooperat. perc.	Multimodal coop., see-through, lifted-seat/satellite/all-around views
Peng(CN)	Grey cam	Logo recogn.	Poor quality, SRSD[47] feat., multiscale scanning locat&class.
Seo(CMU)	Color cam	Workzone recog.	Id. of workzone signs, boundaries of workz., driving cond. changes
Zhang(DE)	Color cam	Pedestrian detec.	Statistic. model upright human body, head/upper/lower, Haar-like
Yu(CN)	Camera	Pedestr. detec.	Variab. handling, heterogeneous feat., HOG LBP[48], MVPPE[49] det.
Guo(CN)	MMW[50] rad.	Road edge rec.	Stripe Hough Transform, extraction of the geometry of road path
Wu(SG)	Stereo cam	Road surface	Nonparametric, depth cue, road scene attrib., planar/nonplanar
Gaikwad(IN)	Grey cam	Lane departure	PLSF[51] contrast impr., Hough t., params. based on Euclidean dist.
Shiau(TW)	Color cam	Illumin. adjust.	Low-cost, efficient algorithm & HW architecture
Iryo(JP)	Infras. cam	Pedestr. behav.	Prob. beh. of pedestrians on flashing green, Monte Carlo simulation
Miseik.(NO)	Cameras	Pedestr. detec.	Joint mobile and static cameras, automated industrial vehicles
Jiang(CN)	-	Pedestr. beh.	TTC[52], differences between driving cultures, midblock crosswalks

Table : ITS Trans. vol. 16, num. 2

47 Statistical Random Sparse Distribution

48 Local Binary Pattern

49 Multi-view-pose part ensemble

50 Milimiter-wave

51 Piecewise Linear Stretching Function

52 Time To Collision

Ref.	Sensor(s)	Task	Key concepts
Mouats(GB)	Stereo vis&therm	Visual odometry	Log-Gabor feat., cosine similarity, Pyramidal Lucas-Kanada track.
Desira.(US)	-	Lane change	Minimizing the disruption of traf. flow, V2V, V2I
Almag.(US)	Color cam	Traffic lights	CVD[53], traffic light standards, fail-safe mechanisms, 400ft
Zhang(CN)	Stereo cam	Speed control	Obstacle det. & track., particle filter, sparse repres., control alg.
Zou(JP)	Cameras	Calibration	Nonoverlapping cams., laser pointer, coplanar/colinear meth.
Green.(GB)	Color cam	Traffic signs	Text-based signs, MSERs[54], HSV thresh., OCR, temporal info.
Mora(UJI)	-	Path planning	PFP[55], Lagrange-Euler formulation, control inputs, real time
Yu(TW)	Infras. cam	Scene detect.	Det. rain+night, traffic flow, salient region det., block seg., SVM
Suhr(KR)	Stereo cam	Road profile	Cubic B-spline, piecewise linear function, Hough t., dynamic prog.
Kim(KR)	Rad.+cam	Situation ass.	Track-to-track fusion, curvilinear coord. conv., lane assesment
Brown(US)	Cam+gyro+map	Vehicle state	Theoretical estimator performance, steady-state Kalman f.

Table : ITS Trans. vol. 16, num. 3

53 Color Vision Deficiency

54 Maximally Stable Extremal Regions

55 Potential Field Projection

Ref.	Sensor(s)	Task	Key concepts
Guo(Toyota)	Stereo cam	Situat. awar.	Unmarked roads, road bound., vehicles, contextual infor., precrash
Malik(AU)	Various	Driving maneuv.	Fuzzy logic, intelligent driver training system, safety rules
Tanig.(JP)	CAN	Driver behav.	Unsuperv. learning, DAA[56] with temporal predic., driving context
Nilsson(SW)	CAN	Driver capabilit.	Assesing when the control can be safe. transferred to the driver
Bresson(FR)	Cam+odom.	SLAM	Monocular SLAM, EKF, minimal Cartesian repr., avoid. lineariz. fail.
Flohr(DE)	Stereo cam	Pedestr. orient.	Joint estimat. of head and body orient., prob. density funct., part. f.
Fortin(FR)	Laser	Veh. det&track.	No detection step, Monte Carlo, geometr. invariant, multitarget
Lee(TW)	NIR cam	Pedestrian det.	Nighttime, IR projector, part-based, block-based segmentation
Huang(CN)	Camera	Logo recog.	CNN, no precise detection or segment. required, pre-training strategy
Ma(CN)	-	Motion plann.	RRT[57], rule-template set, extension of search tree, model-based pred.
Guo(TW)	Camera	Vehicle verif.	Feat. descr., conf. hypothesis, CT[58] subbands, GGD[59], MLE[60]
Shim(KR)	L.+cam...	Auton. driving	Unified Map built with onboard sensors, path planner, commercial
Vicen.(CMU)	Camera	Gaze/distract.	EOR[61], facial track., head pose, gaze est., 3D geom. reasoning
Math.(GB)	Camera	Road marking	Reading rules encoded in road mark., RUSBoost, CRF[62], semantics
Bosetti(IT)	IMU+GPS	Curve behavior	Longitud. speed that ought be used to drive on curvy roads, model
Agostin.(FR)	CAN, GPS	Driv. events	Learning-based, database, discrim. feat., decis. trees, logistic regres.

Table : ITS Trans. vol. 16, num. 4 (I)

[56] Double Articulation Analyzer

[57] Rapidly Exploring Random Tree

[58] Curvelet-Transformed

[59] Generalized Gaussian Distribution

[60] Maximum Likelihood Estimation

ITS Transactions 2015

Ref.	Sensor(s)	Task	Key concepts
Yu(CN)	Laser	Urban facil.	Street light poles, traffic signposts, voxel-based growing, 3D matching
Wang(CN)	V&I info.	Danger eval.	Driver-vehicle-road interact., driving safety field, risk eval., traffic factors
Dong(CN)	Infr. cam	Vehicle type	Semi-supervised CNN, frontal-view, Laplacian filter, softmax, feat. learning
Negru(RO)	Camera	Image enh.	Contrast restoration in fog conditions, math. model, diff. geometry field
Li(CN)	Infr. cam	Vehicle detec.	Multiscale AND-OR graph, inference process, global/local feat., appear.
Wulf(Bosch)	-	HMI	Driver's situation awareness, driving safety, simulator, head-up display
Mercado(NL)	-	Obstac. int.	Velocity obstacle (VO) representation, traj. prediction err.

Table : ITS Trans. vol. 16, num. 4 (II)

ITS Transactions 2015

Ref.	Sensor(s)	Task	Key concepts
Mukhtar(MY)	Review	Vehicle det.	Vision-based vehicle detection for collision avoidance systems
Askel.(NO)	Radar	Veh. track.	Waveform solving, 2D APES estimator, track a laterally moving veh.
Tak(KR)	In-veh+V2V	Safety meas.	Rear-end collision risk, deceleration-based surrogate safety measure
Guan(CN)	LIDAR	Road markings	Automated road marking inventory, 2D GRF[63] images from 3D
Luzheng(CN)	-	Control model	Driver's neuromuscular dyn., QN[64]-based driver lateral ctrl. model
Ohn-Bar(US)	Camera	Veh. detect.	Intracategory diversity, visual/geom. clusters, AdaBoost, orientation
Xu(CN)	CAN	Driver models	Style-oriented driver model for speed control, vehicle test data (VTD)
Kosaka(JP)	Color cam.	Veh. detect.	Nigth, headlights/taillights, LoG, Center Surround Extremas, SVM
Rezaei(IR)	Camera	Veh. detect.	Global Haar-line feat., tail-light, visual symmetry, intervehicle distance
Yoon(KR)	-	Path planning	Reduced states of search space, kinematics-aware node expansion
Gao(CN)	Cam+depth	Pedestr. track.	Multipedestrian, detection in RGB, 3D motion/app./depth feat.
Zou(CN)	Infr. cam	Veh. detect.	Nighttime, headlights, AdaBoost, grouping/track., maximal indp. set
Chen(CN)	-	Veh. control	Tracking a ref. path, hierarchical, three layers, Lyapunov function
Hu(CN)	Infr. cam	Veh. color	Vehicle color recognition, spatial pyramid deep learning, CNN
Cao(CN)	Stereo cam	Path plann.	Local disp. map, V-intercept slope, obst. detect., path planning, A*

Table : ITS Trans. vol. 16, num. 5

[63] Georeferenced Feature

[64] Queuing Network

Topics: putting things in perspective

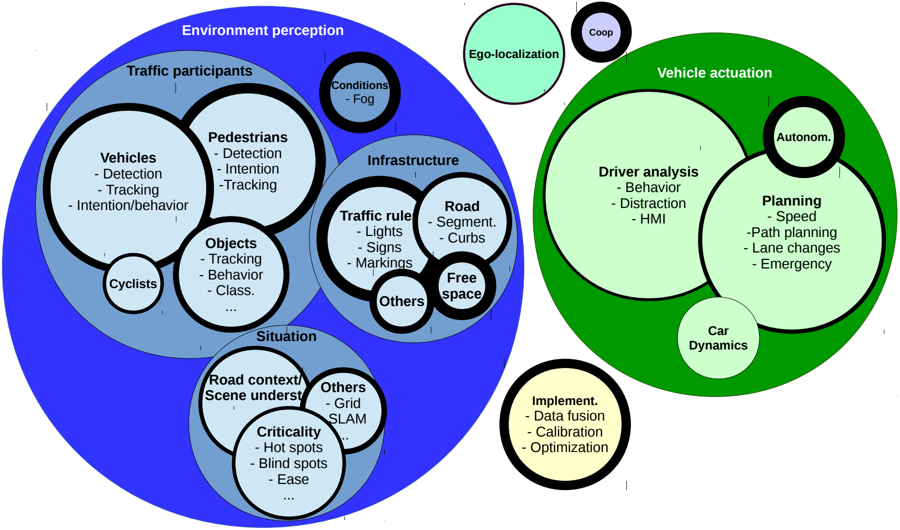

Figure : Topics at ITSC 2015 and ITS Transactions vol. 16. Source: own work

Plan

Let's start with basics

Figure : Intelligent Vehicle based on Visual Information 2.0[65]

[65] David Martín et al. "IVVI 2.0: An intelligent vehicle based on computational perception". In: *Expert Systems with Applications* 41.17 (Dec. 2014), pp. 7927–7944. ISSN: 09574174. DOI: 10.1016/j.eswa.2014.07.002. URL: http://www.sciencedirect.com/science/article/pii/S0957417414003947%20http:

Environment perception: sensors (I)

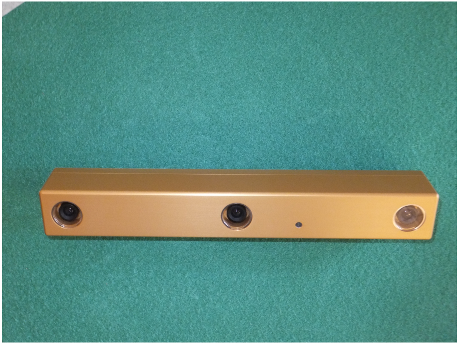

Figure : Stereo-vision system

- **Depth** estimation is straightforward
- Lots of **labelled** data available in the KITTI dataset
- Rigorous **groundtruth** based on their Velodyne LIDAR

Environment perception: sensors (II)

Figure : Expected scenes from stereo and lateral cameras

- **Prolongation** of the field of view (HFOV $\sim 152^\circ$)
- **Depth** estimation is not straightforward
- No **labelled** data or **groundtruth** available

Environment perception: sensors (and III)

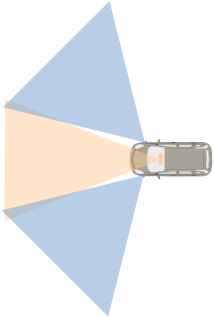

Figure : Joint horizontal field of view with the new cameras

- **Prolongation** of the field of view (HFOV $\sim 152^{\circ}$)
- **Depth** estimation is not straightforward
- No **labelled** data or **groundtruth** available

Vehicles today: ability to make autonomous decisions

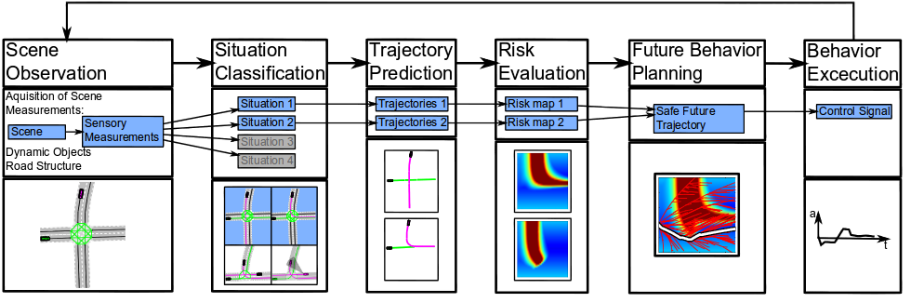

Figure : General approach for situation based risk evaluation and behavior planning[66]

[66] Florian Damerow and Julian Eggert. "Risk-Aversive Behavior Planning under Multiple Situations with Uncertainty". In: *Proc. IEEE International Conference on Intelligent Transportation Systems*. 2015, pp. 656–663. ISBN: 9781467365963. DOI: 10.1109/ITSC.2015.113.

Traffic scene understanding (I)

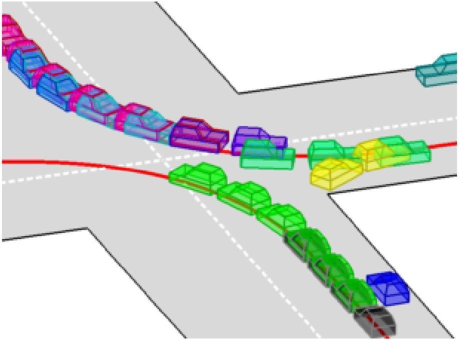

Figure : Inference: Scene Layout and Objects (Result)[67]

[67] Andreas Geiger. "Probabilistic Models for 3D Urban Scene Understanding from Movable Platforms". Ph.D. dissertation. Karlsruher Institut für Technologie, 2013.

Traffic scene understanding (II)

Figure : Intersection scenario[68]

[68] Andreas Geiger and Bernd Kitt. "Object flow: A descriptor for classifying traffic motion". In: *Proc. IEEE Intelligent Vehicles Symposium*. 2010, pp. 287–293. ISBN: 9781424478668. DOI: 10.1109/IVS.2010.5548122.

Traffic scene understanding (III)

Figure : Intersection from a Lane Detector's Point of View[69]

[69] Andreas Geiger. "Probabilistic Models for 3D Urban Scene Understanding from Movable Platforms". Ph.D. dissertation. Karlsruher Institut für Technologie, 2013.

Traffic scene understanding (III)

Figure : Intersection from a Lane Detector's Point of View[69]

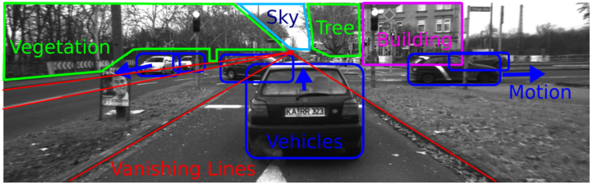

Figure: Intersection from a Human's Point of View

[69] Andreas Geiger. "Probabilistic Models for 3D Urban Scene Understanding from Movable Platforms". Ph.D. dissertation. Karlsruher Institut für Technologie, 2013.

Traffic scene understanding (and IV)

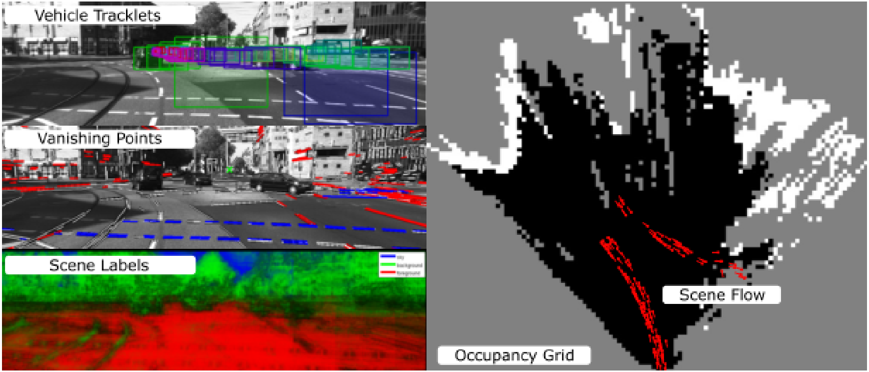

Figure : Video-based Image Cues (Inputs)[70]

[70] Andreas Geiger. "Probabilistic Models for 3D Urban Scene Understanding from Movable Platforms". Ph.D. dissertation. Karlsruher Institut für Technologie, 2013.

Situation assessment (I)

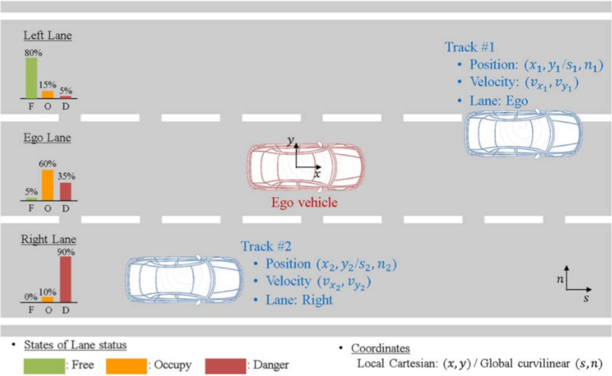

Figure : Example of object and situation assessment[71]

[71] Junsoo Kim et al. "Curvilinear-Coordinate-Based Object and Situation Assessment for Highly Automated Vehicles". In: *IEEE Transactions on Intelligent Transportation Systems* 16.3 (2015), pp. 1559–1575.

Situation assessment (and II)

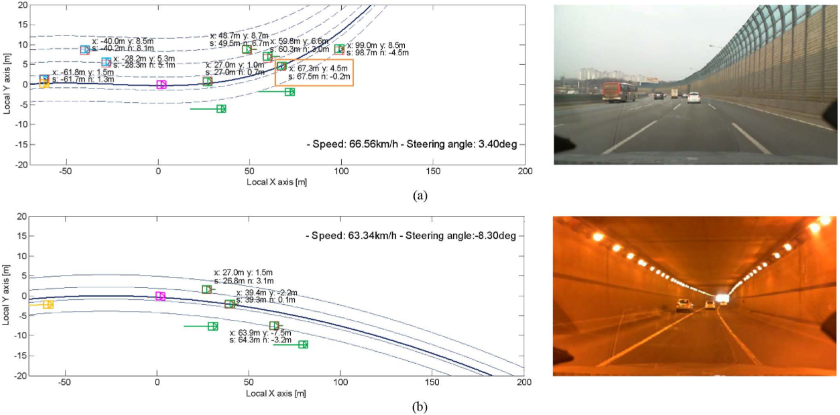

Figure : Object assessment result in curved road cases[72]

[72] Junsoo Kim et al. “Curvilinear-Coordinate-Based Object and Situation Assessment for Highly Automated Vehicles”. In: *IEEE Transactions on Intelligent Transportation Systems* 16.3 (2015), pp. 1559–1575.

Situation awareness pipeline

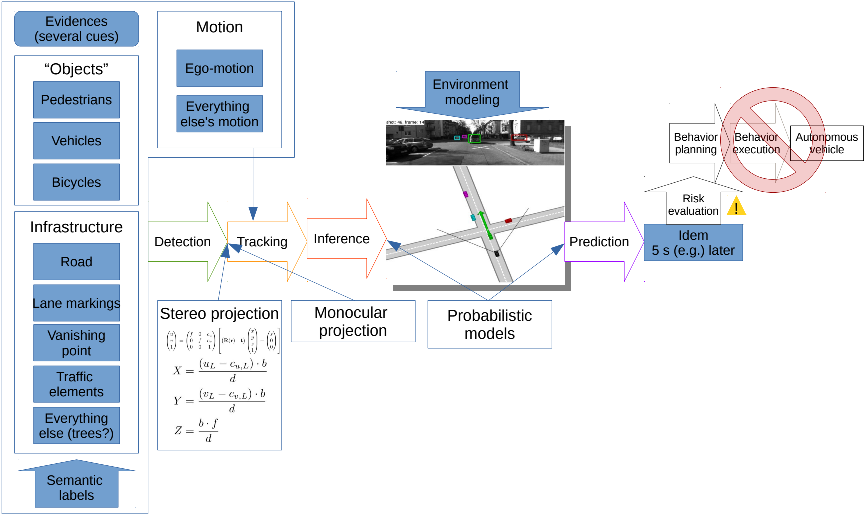

Figure : Mind map depicting my (expected) future work. Source: myself

But... is behavior planning so far away? (I)[73]

Figure : Example results

Red	Physical road boundary
Yellow/Cyan	Virtual lane markings
Blue	Suggested path
Green	Virtual emergency lane

[73] Chunzhao Guo et al. "A Multimodal ADAS System for Unmarked Urban Scenarios Based on Road Context Understanding". In: *IEEE Transactions on Intelligent Transportation Systems* 16.4 (2015), pp. 1690–1704.

But... is behavior planning so far away? (and II)[74]

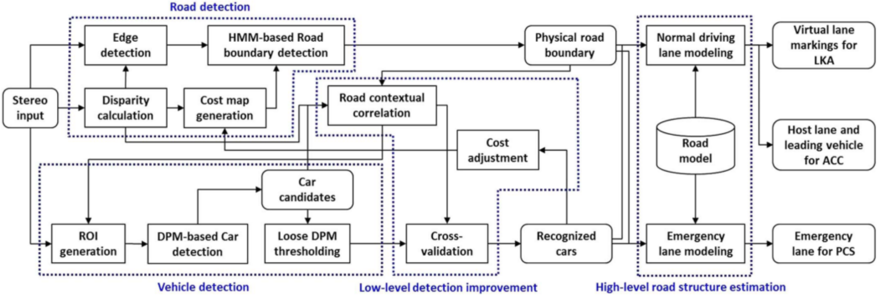

Figure : Flow diagram of the system

[74] Chunzhao Guo et al. "A Multimodal ADAS System for Unmarked Urban Scenarios Based on Road Context Understanding". In: *IEEE Transactions on Intelligent Transportation Systems* 16.4 (2015), pp. 1690–1704.

Objects & Context: a chicken-and-egg problem (I)

"We recognize a car because it's on the road. But how do we recognize a road? — because there are cars!"[75]

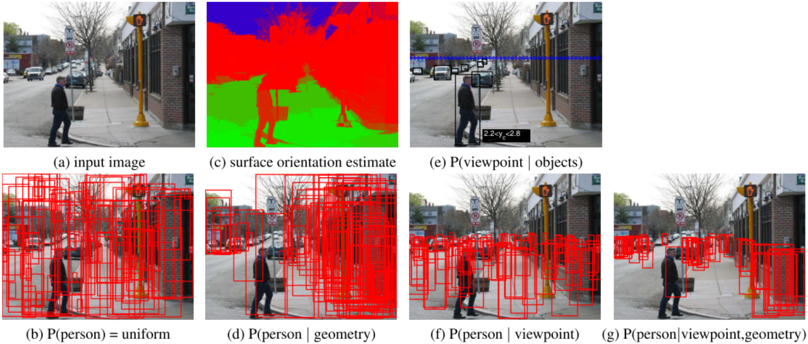

Figure : Pedestrian detection with/without evidences

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[75] Derek Hoiem, Alexei A. Efros, and Martial Hebert. "Putting objects in perspective". In: *International Journal of Computer Vision* 80.1 (2008), pp. 3–15. ISSN: 09205691. DOI: 10.1007/s11263-008-0137-5.

Objects - Context: a chicken-and-egg problem (and II)

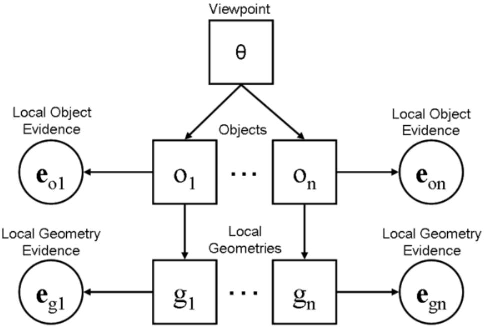
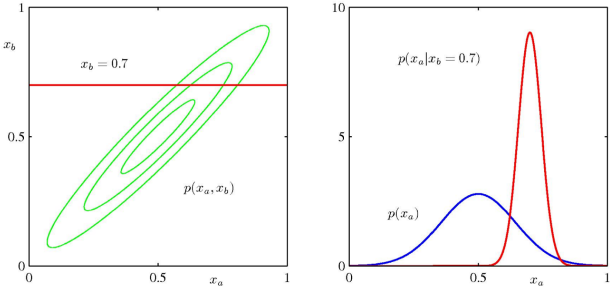


Figure : Graphical model of conditional independency for viewpoint, object identities and the 3D geometry of surfaces surrounding the objects[76]

[76] Derek Hoiem, Alexei A. Efros, and Martial Hebert. "Putting objects in perspective". In: *International Journal of Computer Vision* 80.1 (2008), pp. 3–15. ISSN: 09205691. DOI: 10.1007/s11263-008-0137-5.

Managing uncertainty: probabilistic theory (I)



joint, marginal, conditional probability

Figure : Illustration of joint, marginal and conditional probabilities

Managing uncertainty: probabilistic theory (and II)

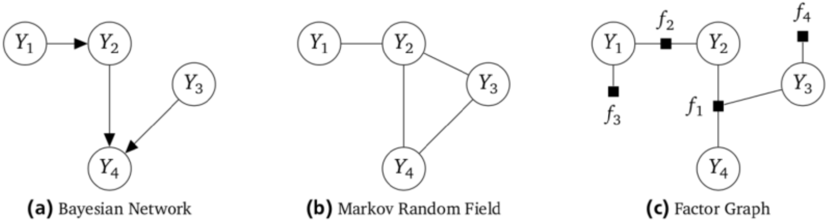


Figure : Graphical models

Managing uncertainty: a toy example

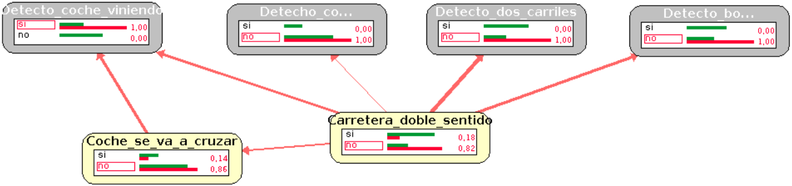


Figure : Toy Bayes Network with UNED's ELVIRA software

Managing uncertainty: a real example[77]

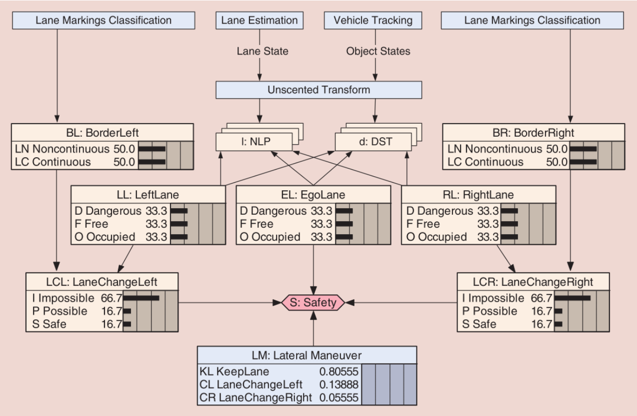


Figure : Bayesian network with chance nodes (ocher), a utility node (red), and a decision node (blue) for deriving lane change maneuver decisions.

[77] Robin Schubert and Gerd Wanielik. "A unified bayesian approach for object and situation assessment". In: *IEEE Intelligent Transportation Systems Magazine* 3.2 (2011), pp. 6–19. ISSN: 1939-1390. DOI: 10.1109/MITS.2011.941331.

Plan

Situation awareness pipeline (again)

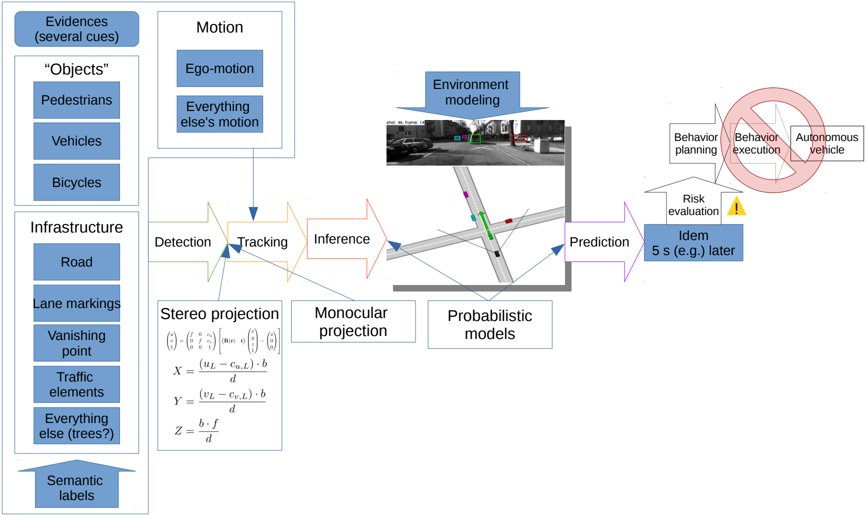
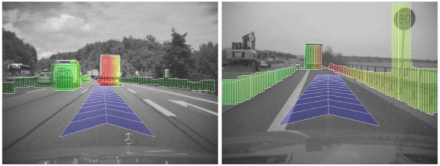


Figure : Mind map depicting my (expected) future work. Source: myself

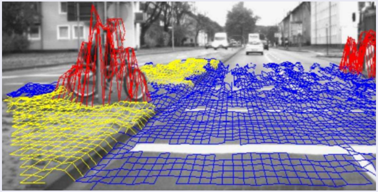
Obstacle detection using stereo vision (I)

Probabilistic occupancy maps: Stixel world



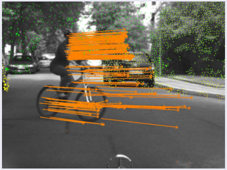
(a) Highway (b) Construction site

Digital elevation maps: distance from the road surface

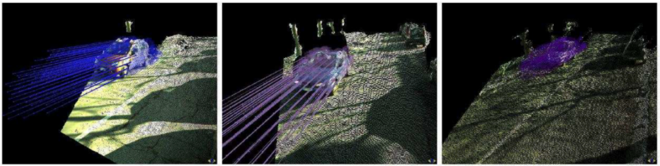


Obstacle detection using stereo vision (and II)[78]

Scene flow segmentation: 6D vision - each 3D point is tracked



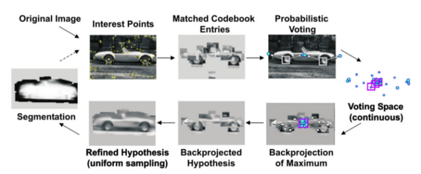
Geometry-based cluster



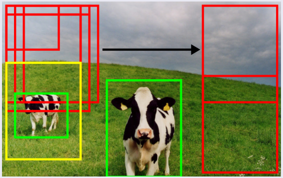
[78] Nicola Bernini et al. "Real-time obstacle detection using stereo vision for autonomous ground vehicles: A survey". In: *Proc. IEEE International Conference on Intelligent Transportation Systems*. 2014, pp. 873–878. ISBN: 978-1-4799-6078-1. DOI: 10.1109/ITSC.2014.6957799.

Object detection methods (I)

Feature-based methods: Implicit shape model



Sliding-window-based methods: Viola-Jones, Dalal-Triggs, DPM



Object detection methods (II)

Proposal Regions + complex predictor (CNN)

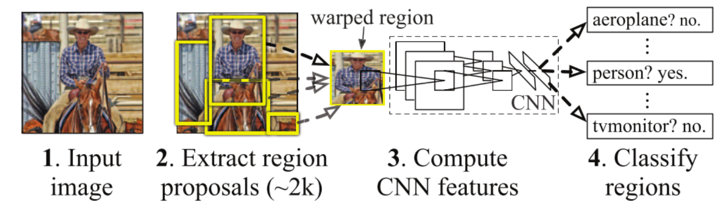


Figure : R-CNN: object detection system overview[a]

[a] Ross Girshick et al. "Region-based Convolutional Networks for Accurate Object Detection and Segmentation". In: *Proc. IEEE Conference on Computer Vision and Pattern Recognition*. 2014, pp. 580–587. ISBN: 978-1-4799-5118-5. DOI: 10.1109/TPAMI.2015.2437384.

What is happening in object detection? (I)

Deep Learning is leading to **large improvements**

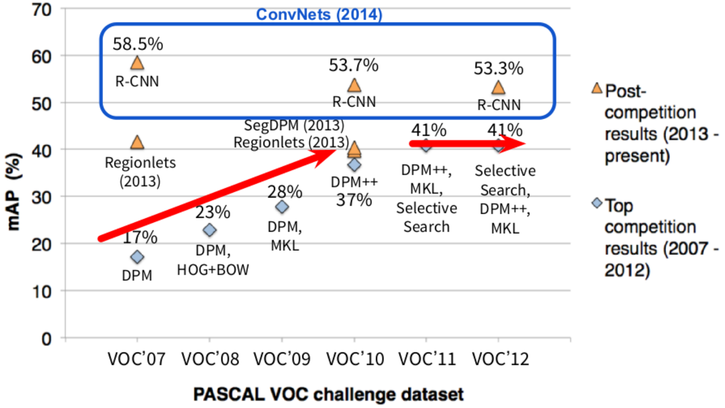


Figure : PASCAL Visual Object Classes Challenge - Results

What is happening in object detection? (II)

But recently, the Convolutional Neural Networks (CNNs) [50] have achieved better accuracy results than BoW. These networks have a more sophisticated structure than standard representations, comprising several layers of non-linear feature extractors. That is the reason they are called deep, in contrast with classical representation that are called shallow. Their structure is handcrafted and they contain a very large number of parameters learnt from data. CNN have demonstrated their performance [22][31][65][71][76], which is significantly better than standard image encodings [9], when they have been applied to standard image classification and object detection benchmark datasets such as ImageNet ILSVRC [20] and PASCAL VOC [25].

Figure : Fidalgo Fernández, Eduardo. Ph. D. dissertation. Universidad de León.

A CNN is a **special case** of a Multi-Layer-Perceptron.

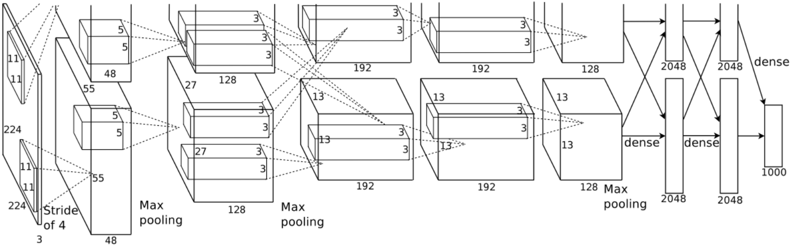


Figure : "Alexnet" Convolutional Neural Network[79]

[79] Alex Krizhevsky, Ilya Sutskever, and Geoffrey E Hinton. "ImageNet Classification with Deep Convolutional Neural Networks". In: *Advances In Neural Information Processing Systems*. 2012, pp. 1097–1105. ISBN: 9781627480031. arXiv: 1102.0183.

So... why is everybody so excited?

Figure : Convolutional Neural Network

- All the way from pixels to classifier is **learned**
- One layer extracts features from output of previous layer
- Features are no longer hand-crafted!
- **Not everything is happy**: CNN are slow unless they use GPU and... we really don't know what they do.

An approach for object classification (I)

R-CNN: Regions with CNN features

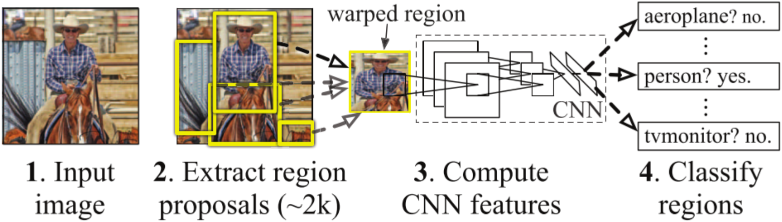
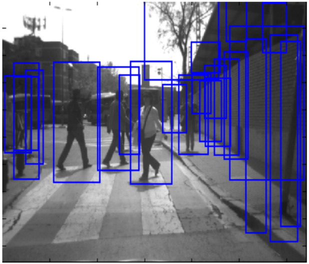


Figure : R-CNN: object detection system overview[80]

[80] Ross Girshick et al. "Region-based Convolutional Networks for Accurate Object Detection and Segmentation". In: *Proc. IEEE Conference on Computer Vision and Pattern Recognition*. 2014, pp. 580–587. ISBN: 978-1-4799-5118-5. DOI: 10.1109/TPAMI.2015.2437384.

An approach for object classification (II)


(e) ROIs resultantes

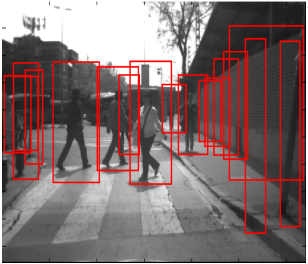

(f) ROIs no elevadas

Figure : Dr. Musleh's approach for obstacle detection[81]

- Objects are supposed to be homogeneous in its disparity value.
- Sub-pixel accuracy obtained by SGBM is completely wasted.

[81] Basam Musleh. "Análisis de entornos urbanos de tráfico y estimación del movimiento del vehículo para el desarrollo de sistemas de ayuda a la conducción". Ph.D. dissertation. Universidad Carlos III de Madrid, 2014.

An approach for object classification (III)

Another approach: selective search[82] segmentation - Very Slow!

Figure : Object proposal from edges

[82] J. R R Uijlings et al. "Selective search for object recognition". In: *International Journal of Computer Vision* 104.2 (2013), pp. 154–171. ISSN: 09205691. DOI: 10.1007/s11263-013-0620-5.

One more approach:

- Object proposals from edges
- Fast edge detection with structured forests[83]. Color or color+depth information can be used!

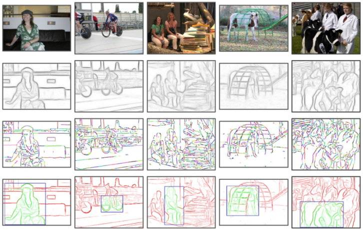


Figure : Object proposal from edges

[83] Piotr Dollar and C. Lawrence Zitnick. "Structured Forests for Fast Edge Detection". In: *Proc. IEEE International Conference on Computer Vision*. 2013, pp. 1841–1848. ISBN: 978-1-4799-2840-8. DOI: 10.1109/ICCV.2013.231. arXiv: arXiv:1406.5549v1. URL: http://www.mendeley.com/catalog/structured-forests-fast-edge-detection/.

An approach for object classification (and V)

Results (check videos):

- Default training for VOC Pascal classes! (own training has not been performed yet)
- No depth information
- Using the smallest net (because of Tesla restrictions)
- Classification (CNN) running on GPU with a MATLAB wrapper. Disparity running on OpenCV with a MATLAB wrapper. Everything else running on MATLAB.
- Times:
  - Edges: 180 ms (MATLAB)
  - Boxes: 230 ms (MATLAB)
  - Classification: 140 ms (with thousands of region proposals)
- OpenCV 3.0 has a new function for structured-forest edges.

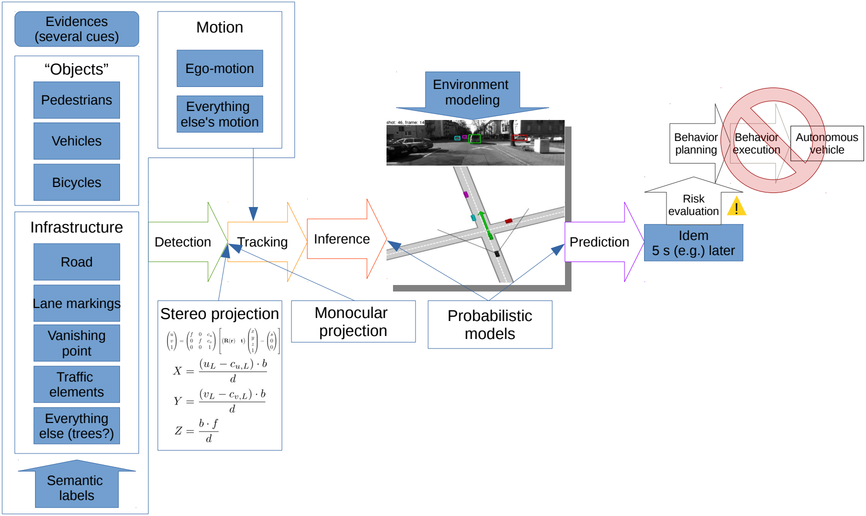


Figure : Mind map depicting my (expected) future work. Source: myself

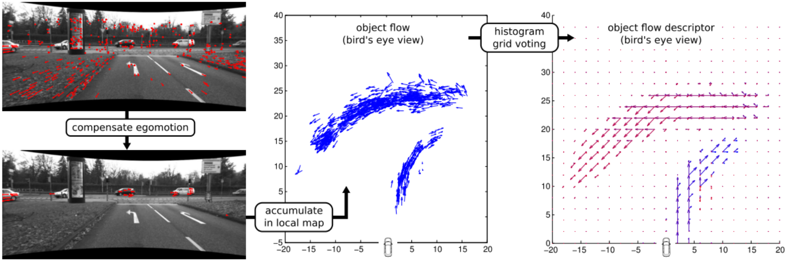


Figure : Scene flow overview[84]

[84] Andreas Geiger and Bernd Kitt. "Object flow: A descriptor for classifying traffic motion". In: *Proc. IEEE Intelligent Vehicles Symposium*. 2010, pp. 287–293. ISBN: 9781424478668. DOI: 10.1109/IVS.2010.5548122.

Road detection[85]

1. **Image preprocessing**. Obstacles can be removed, shadows weakened, image area truncated, etc.
2. **Feature extraction**. Color and texture statistics for road segmentation, road patch classification or curb detection. Evidence for lane marks for lane detection.
3. **Road/lane model fitting**. A road and lane hypothesis is formed by fitting a road/lane model to the evidence gathered.
4. **Temporal integration**. The road and lane hypothesis is reconciled with road/lane hypotheses from the previous frame.

[85] Aharon Bar Hillel et al. "Recent progress in road and lane detection: a survey". In: *Machine Vision and Applications* 25.3 (2014), pp. 727–745. ISSN: 09328092. DOI: 10.1007/s00138-011-0404-2.

The End