Driver Assistance Systems (DAS)

Short Overview

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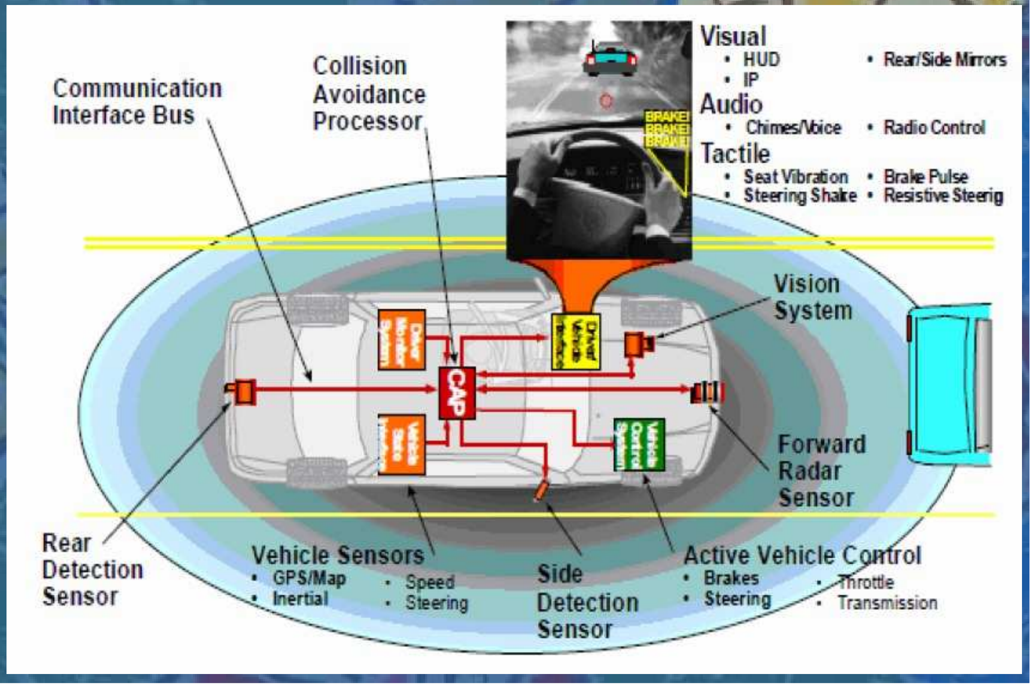
What is DAS?

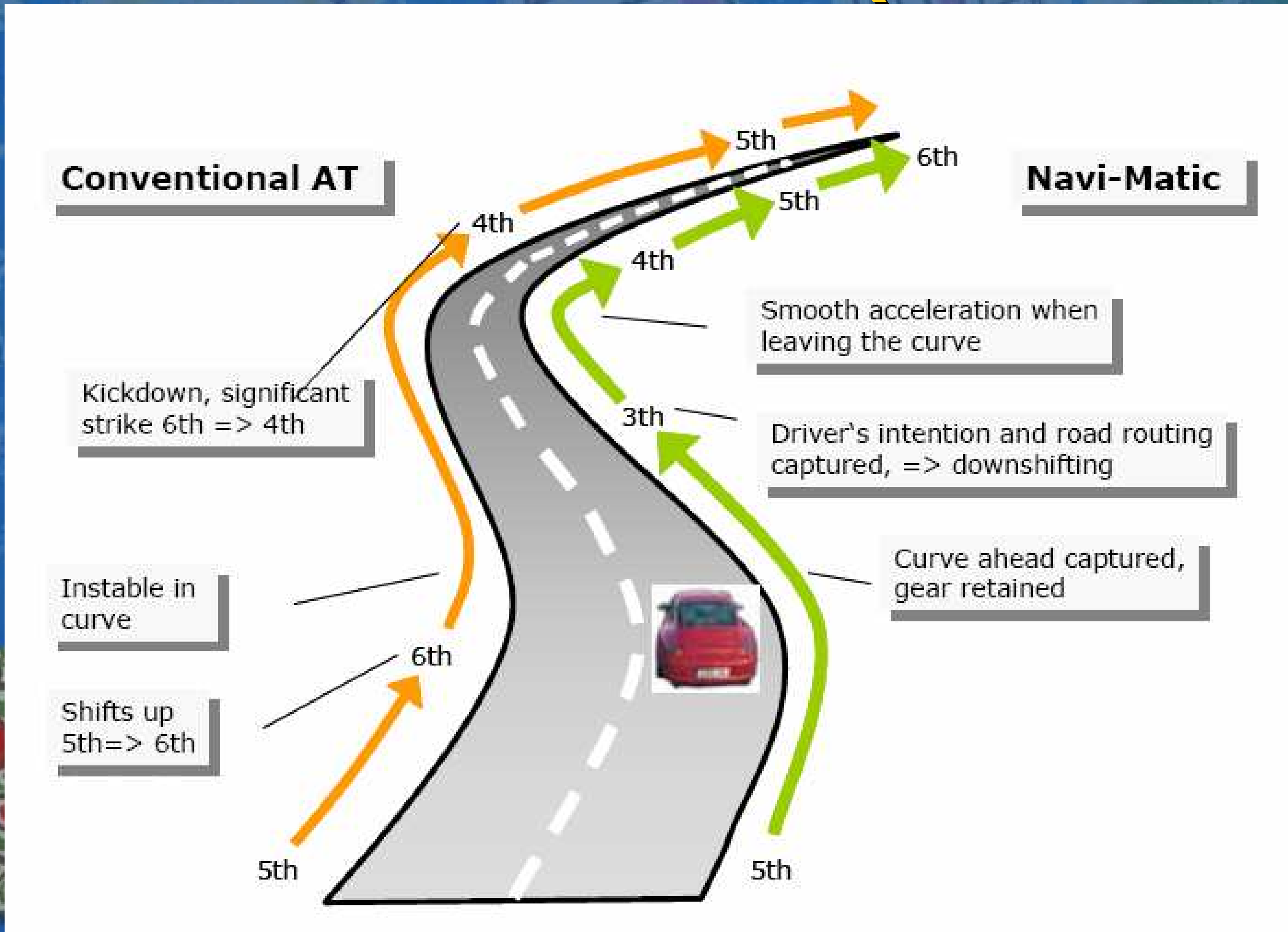
- DAS: electronic systems helping the driving of a vehicle
- ADAS (advanced DAS): the collection of systems and subsystems on the way to a fully automated driving system
- Vision-based DAS: DAS using optical sensors



Purposes of DAS

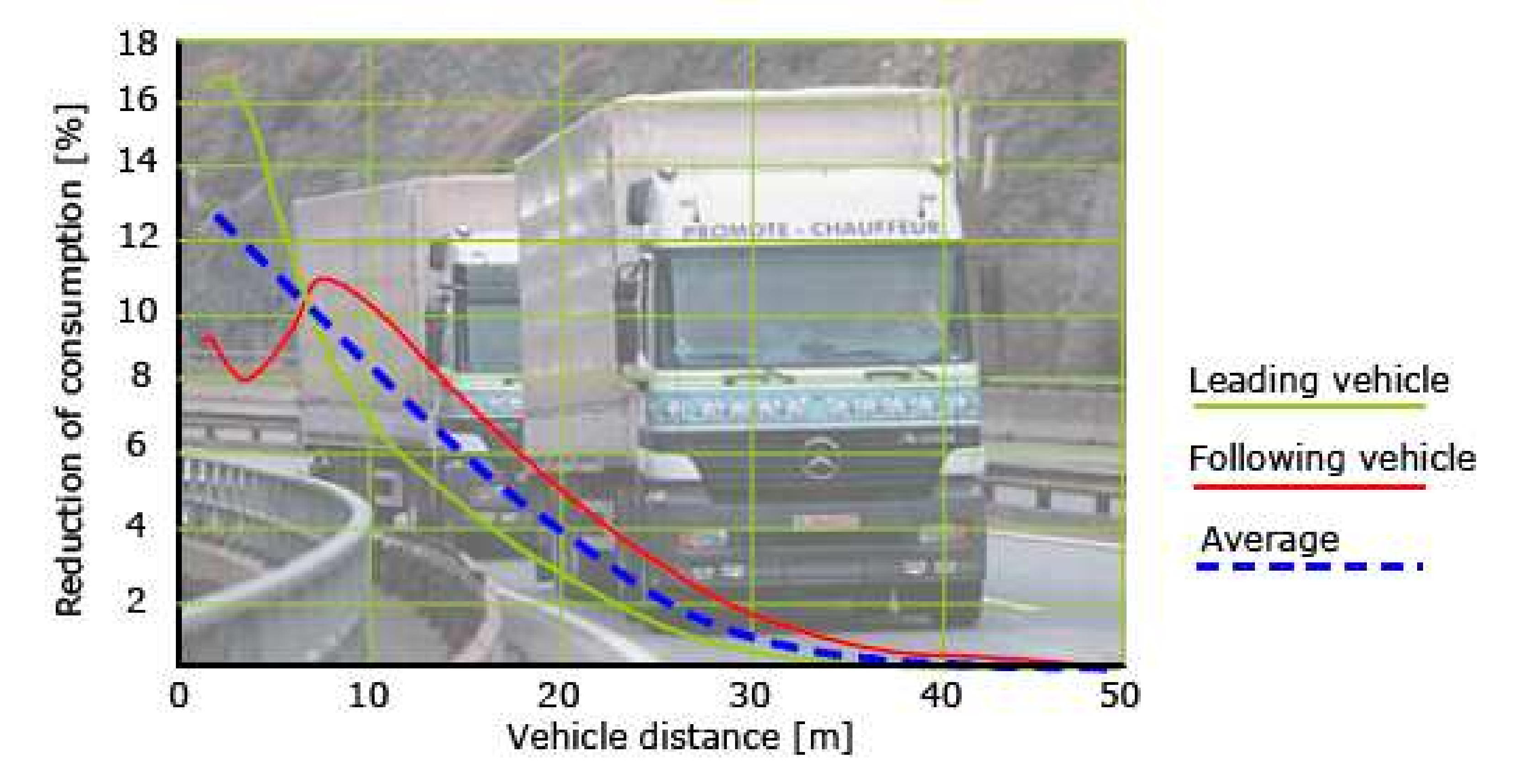
- Economy:
  - Lower fuel consumption
  - Lower cost of ownership
  - Less polution of environment
- Comfort:
  - Easier driving
  - Information about traffic
  - Route planning
- Safety:
  - Lower risk of accidents
  - Less serious accidents

Lower Consumption by Navi-Matic (Aisin AW)



More economic gear selection based on digital map information

Drive in line



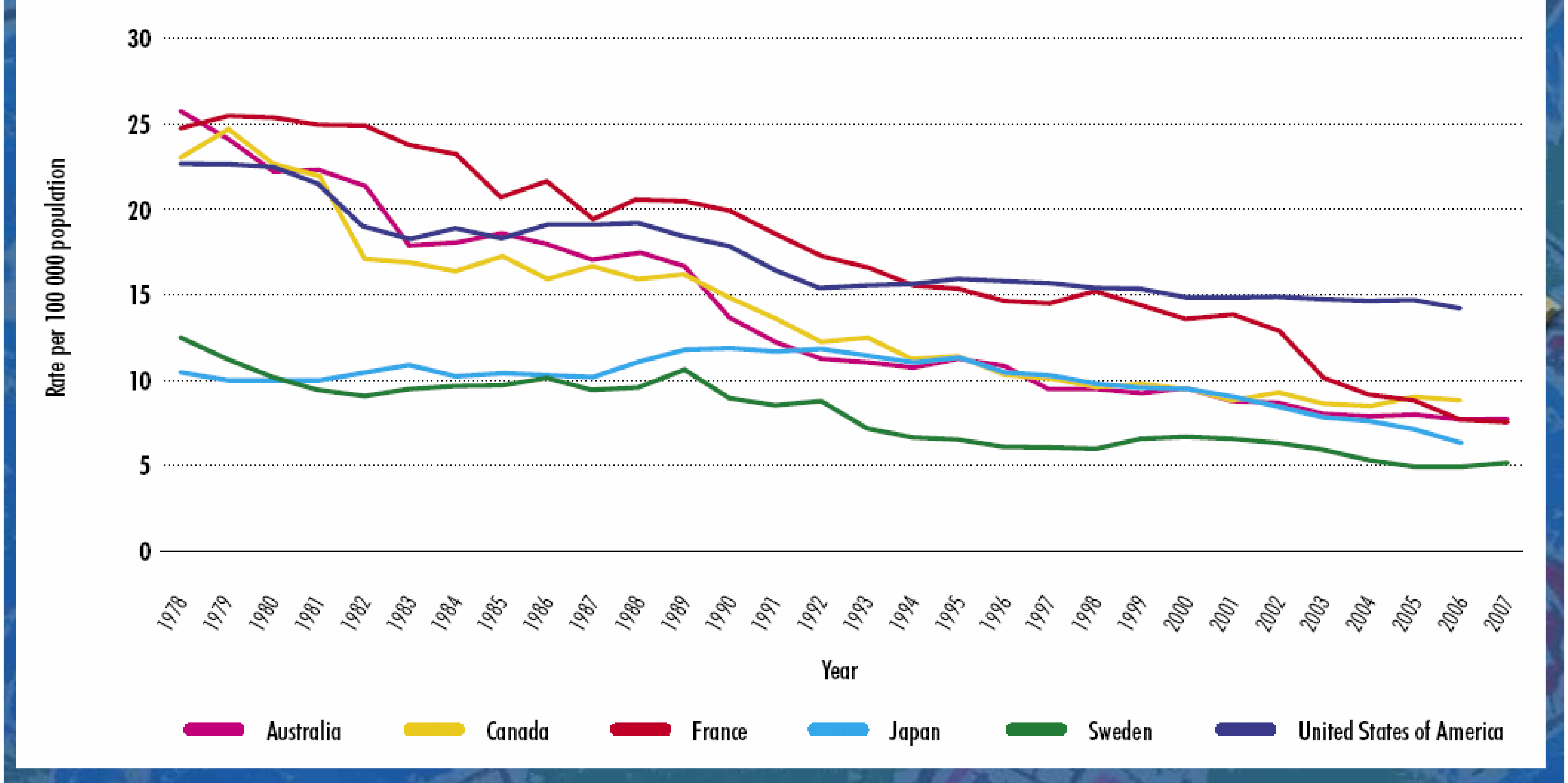
Regulations

- The European Union's Transport Policy 2011 – 2020
  - reduce fatalities on European roads by half over the next decade.
  - introduces a focus on the reduction of severe injuries;

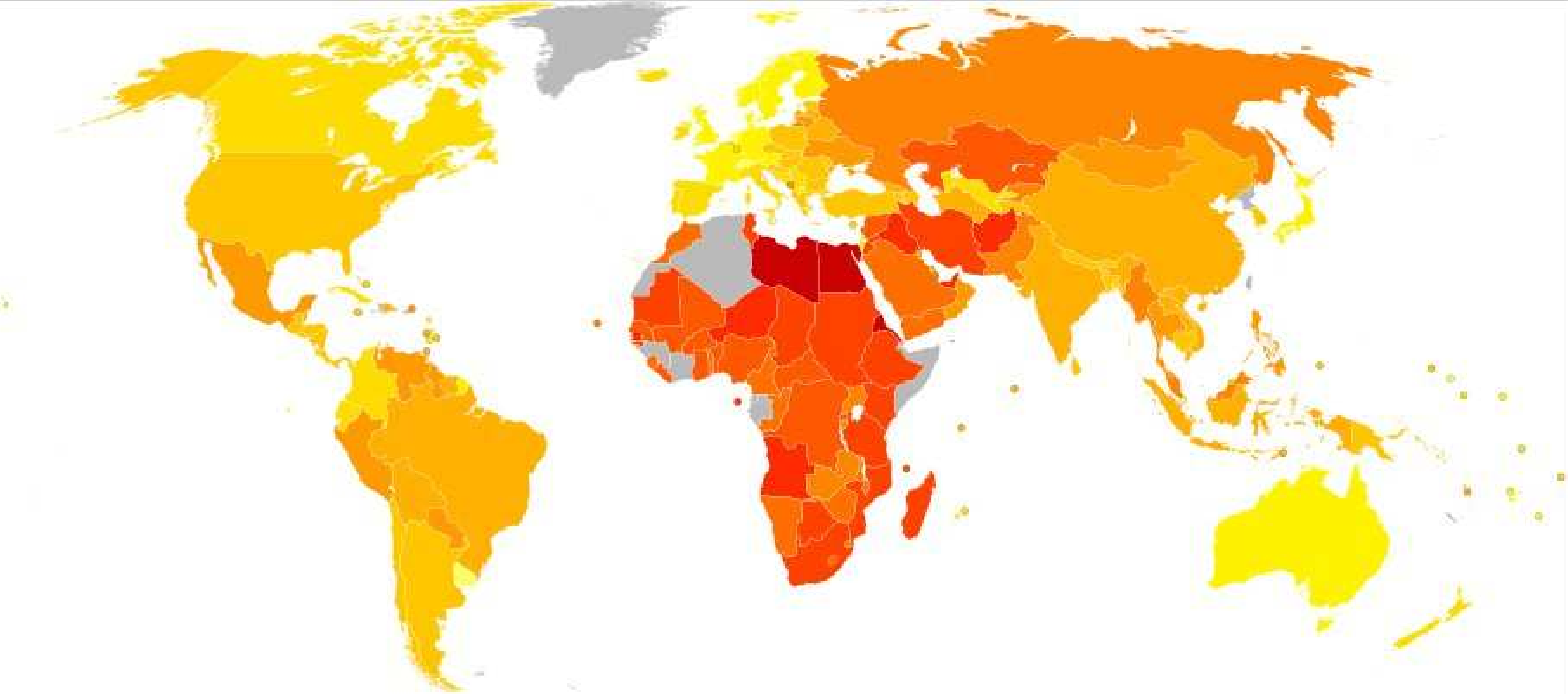
- The EU Safety Regulation makes ESP mandatory as of November 2014 for all vehicle classes.

(Since ESP is an important component of

Road Fatality Trends in High-income Countries



Road Fatalities Worldwide



- Road fatalities per 100,000 inhabitants per year, 2000, Global Status Report On Road Safety, WHO

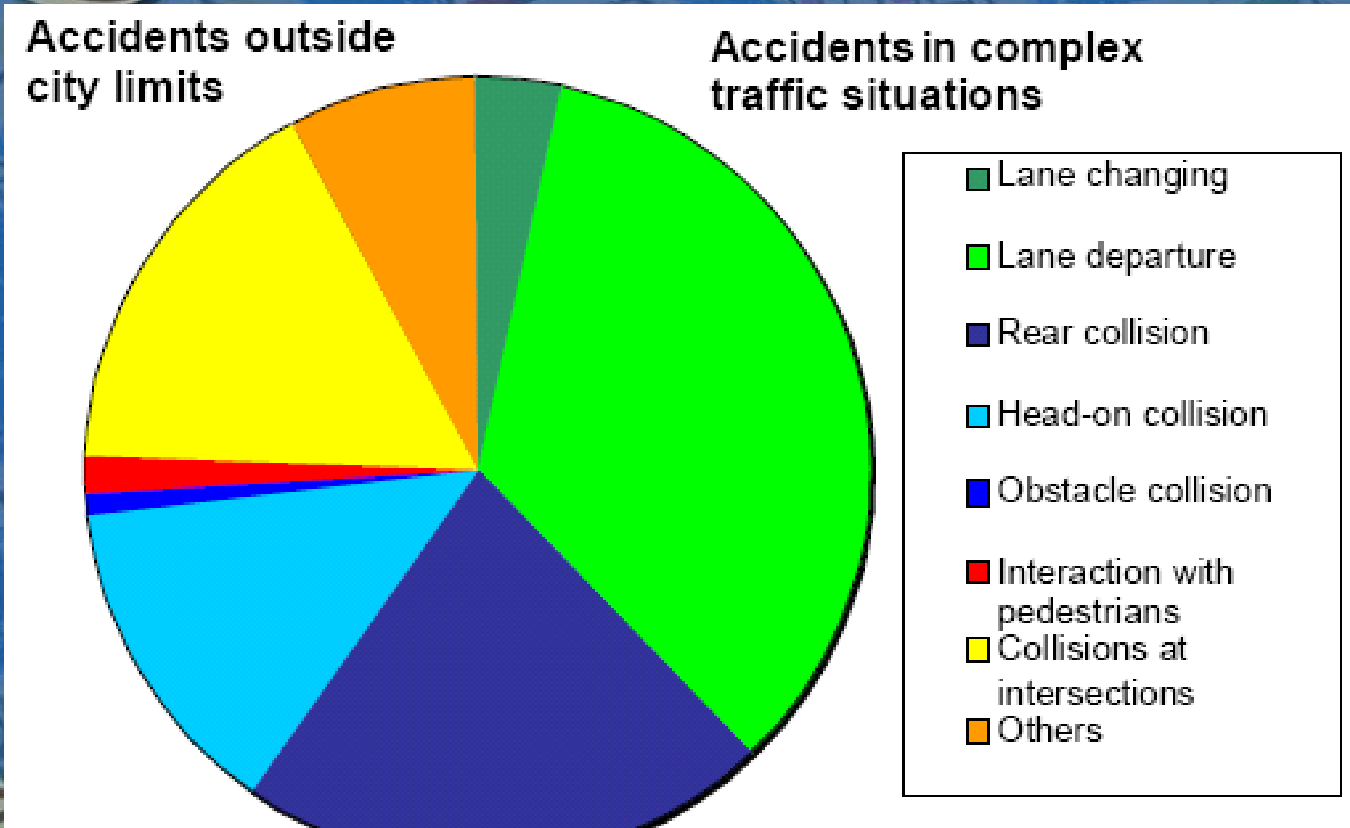
Some Statistics

- The main cause of 90% of traffic accidents is human error (German Federal Statistical Office, 2007).

- Accidents with physical injuries can be attributed either to inappropriate speed (16%) or to insufficient stopping distance (12%).

- 40% of all people killed in road traffic were due to unadapted speed (2010, Germany)

Accidents is Complex Traffic Situations



What are the real causes behind human errors?

Unseen obstacles, misunderstood information, too long reaction time, alcohol...?

Traffic Psychology

- Traffic psychology is primarily related to the study of the behavior of road users and the psychological processes underlying that behavior (Rothengatter, 1997)
- Important question is the relationship between
  - behavior of drivers
  - cars' features and equipments
  - environment
  - accidents

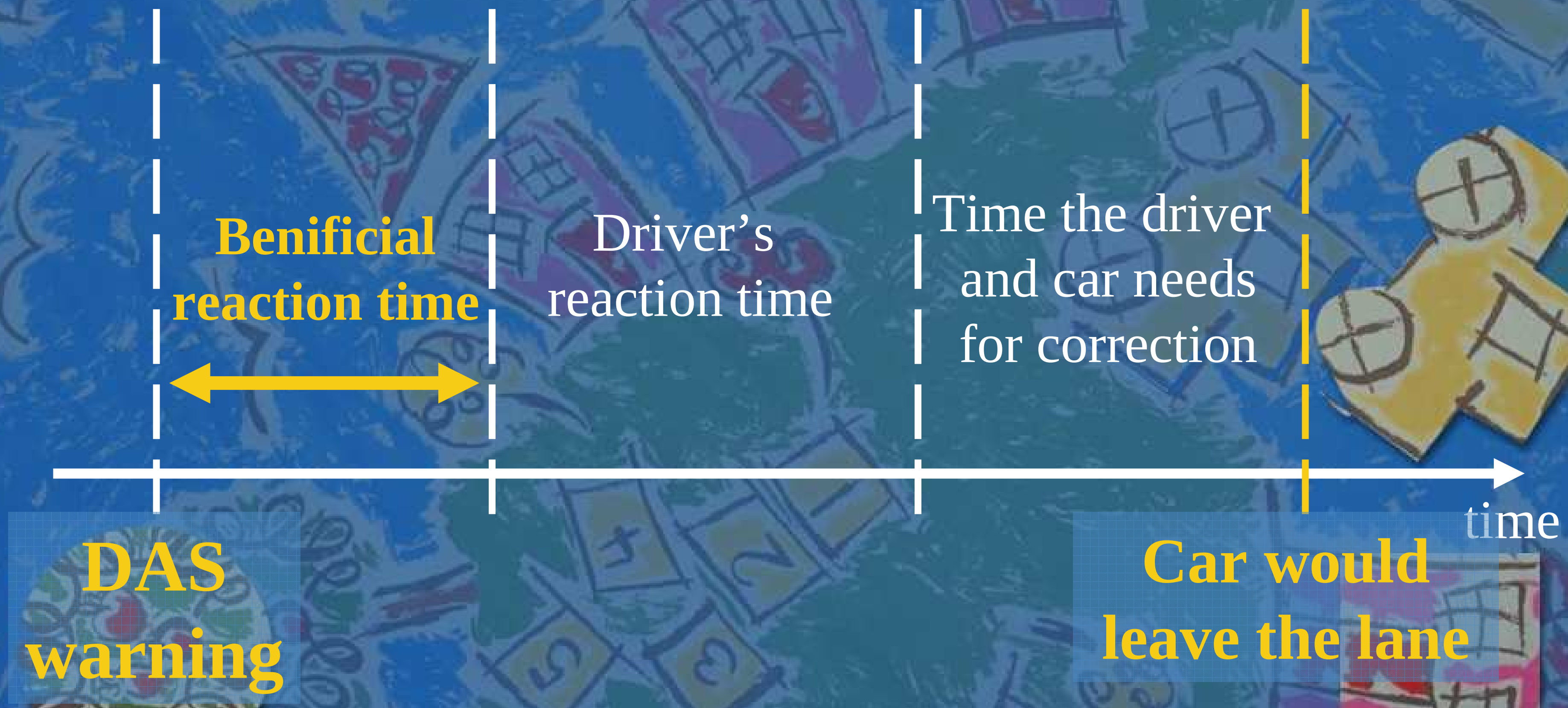
Example 1: Reaction time of drivers and its effect on breaking distance

	figures		
	Most possible	2% (only 2% are faster)	98% (only 2% are slower)
Reaction Without view turning With view turning 0.5-5° With view turning > 5°	 0.64 1.12 1.25	 0.36 0.68 0.77	 0.78 1.33 1.48
Response time	0.05	0.03	0.06
Build-up time	0.17	0.14	0.18

Reaction time (s) and distance (m) at 100km/h

0,1	0,2	0,5	0,67	1	1,5
2,778	5,556	13,89	18,6	27,78	41,67

Example 2: Quality measure for lane departure alert systems



DARPA *(Defense Advanced Research Projects Agency)*

prize competitions for driverless vehicles

- 2004: only 12km of the desert route succeeded
- 2005: 5 cars ran the whole 212km off-road route
- 2007: 6 teams succeeded the 96km urban area course, the winner with 23km/h average speed

Tatran Racing, 1st Place of Urban Challenge 2007

A description of the sensors incorporated onto the Tartan Racing Robots

Sensor	Characteristics
Applanix POS-LV 220/420 GPS / IMU	• sub-meter accuracy with Omnistar VBS corrections • tightly coupled inertial/GPS bridges GPS-outages
SICK LMS 291-S05/S14 Lidar	• 180º / 90º x 0.9º FOV with 1º / 0.5º angular resolution • 80m maximum range
Velodyne HDL-64 Lidar	• 360º x 26º FOV with 0.1º angular resolution • 70m maximum range
Continental ISF 172 Lidar	• 12º x 3.2º FOV • 150m maximum range
IBEO Alasca XT Lidar	• 240º x 3.2º FOV • 300m maximum range
Ma/Com Radar	• 80º FOV • 27m maximum range
Continental ARS 300 Radar	• 60º / 17º x 3.2º FOV • 60m / 200m maximum range
MobilEye Vision System	• 45º x 45º FOV • ~35m effective range

History: first commercial appearances

- 1970s - ABS (Anti-lock Braking System - Bosch)
- 1990s – ESC/ESP (Electronic Stability Control/Program - Bosch)
- Early 1990s
  - Park Distance Control
  - GPS based navigation systems
- 1995 ACC (Adaptive Cruise Control - Mitsubishi)
- 2001 Lane keeping support (Nissan)
- 2002 Night Vision (Toyota)
- 2003 Intelligent Parking Assist System (Toyota)
- 2003 Collision Mitigation Brake System (Honda)
- 2005 Blind Spot Detection (Volvo)
- 2007 Around View Monitor (Nissan)
- 2008 Traffic Sign Recognition (MobilEye and Continental)
- 2009 Adaptive Light Control (Mercedes)
- 2009 Attention Assist - Driver drowsiness detection (Mercedes)
- 2011 Pedestrian Detection (Volvo)

Sensors for DAS

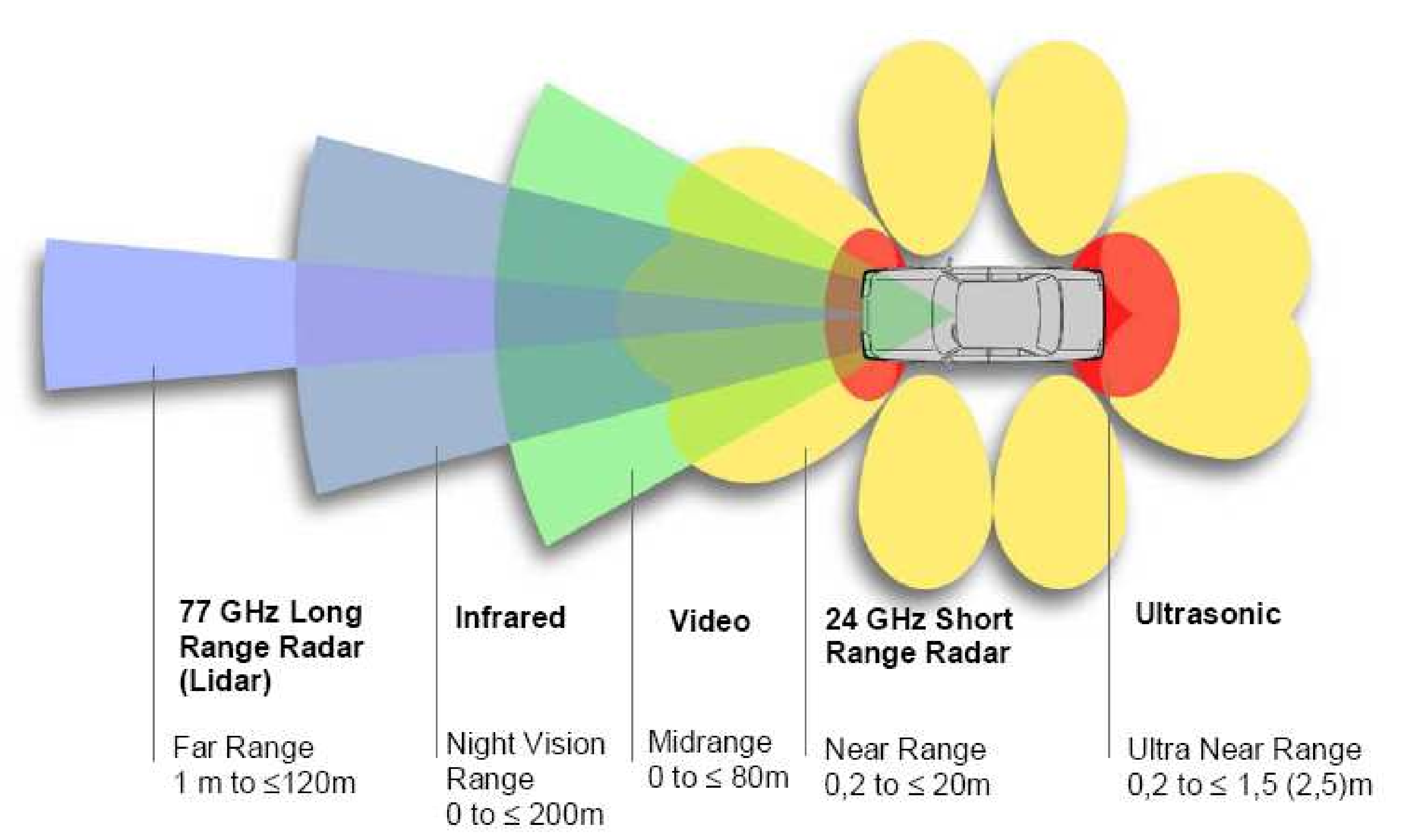
- Rotation (yaw) and acceleration sensors
- Wheel speed sensor
- Steering wheel angle sensor
- Mono or Stereo Camera
- Infra camera
- Ultrasound
- Radar
- Lidar
- GPS (incl. map based data)
- Combination of these...

In focus of vision-based DAS (Mono or Stereo Camera, Infra camera)

Sensors for DAS

- Night vision (infra camera)
- Around view monitor (camera)
- Collision warning (radar, lidar, and camera)
  - Object (pedestrian) detection (camera)
- Lane departure alert, Lane change assistance, Lane keeping - Automatic steering (camera)
- Adaptive light control (camera)
- Adaptive cruise control (radar and camera)
- Parking systems (radar, ultrasound and camera)
- Traffic Sign recognition (camera)
- Blind spot detection (radar/camera)
- Driver drowsiness detection (steering and camera)

Sensor ranges



Vision-based DAS

- Pros:
  - Rich information source
  - Can directly enhance visual sensing
  - Wide field of application
- Cons:
  - Expensive (special cameras, processors)
  - High computational load (high power consumption)

Night Vision

- IR sensors
  - Active (Mercedes), ~150m
  - Passive (BMW), ~300m
  - Combined with motion (pedestrian) detection (Night Vision Assist Plus)

A better view for the driver…

- 360 degree view to help parking
- Integration of images of 4 (or more) cameras
- Image geometry transformations
  - Warping
  - Homography

Bird view of the car from
the cockpit of an Infinity

Homography (H)

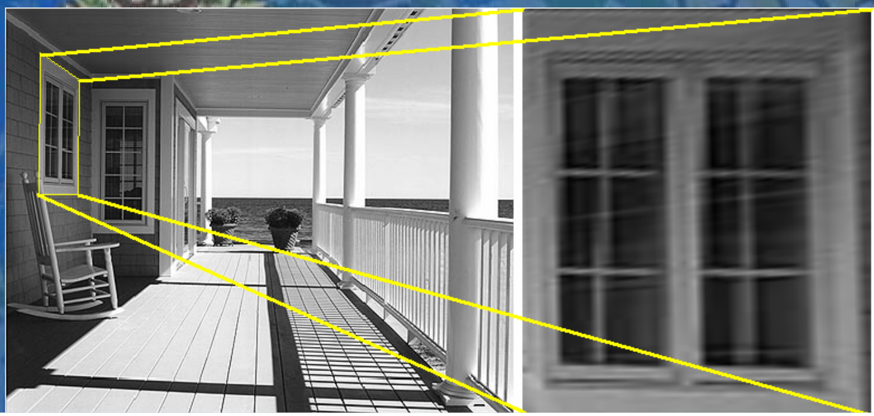
- Can be applied for plain objects
- Transformation from Camera 1 to Camera 2:

$$\mathbf{X}_2 = H\mathbf{X}_1 \quad \mathbf{X}_1, \mathbf{X}_2 \in \mathbb{R}^3$$

- Using homogeneous coordinates:

$$\lambda_1 \mathbf{x}_1 = \mathbf{X}_1, \quad \lambda_2 \mathbf{x}_2 = \mathbf{X}_2$$

- By image coordinates: $\lambda_2 \mathbf{x}_2 = H \lambda_1 \mathbf{x}_1$
- H is estimated by calibration



How DAS understands the visual information?

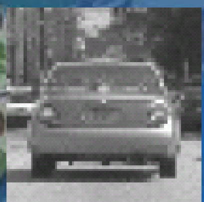
- Use only 2D information?
  – Classical 2D pattern recognition
- Use motion information?
  – Consider the ego-motion of the camera
  – Image motion greatly depends on the 3D structure of the scene
- or combine the two approaches...

Boosted classifier for car detection

- Large pool of weak classifiers
- AdaBoost to select and combine weak classifiers

Paul Viola and Michael Jones, “Robust Real-time Object Detection” *International Journal of Computer Vision* (IJCV), 2004.

David C. Lee, and Takeo Kanade. "Boosted Classifier for Car Detection." 2007.

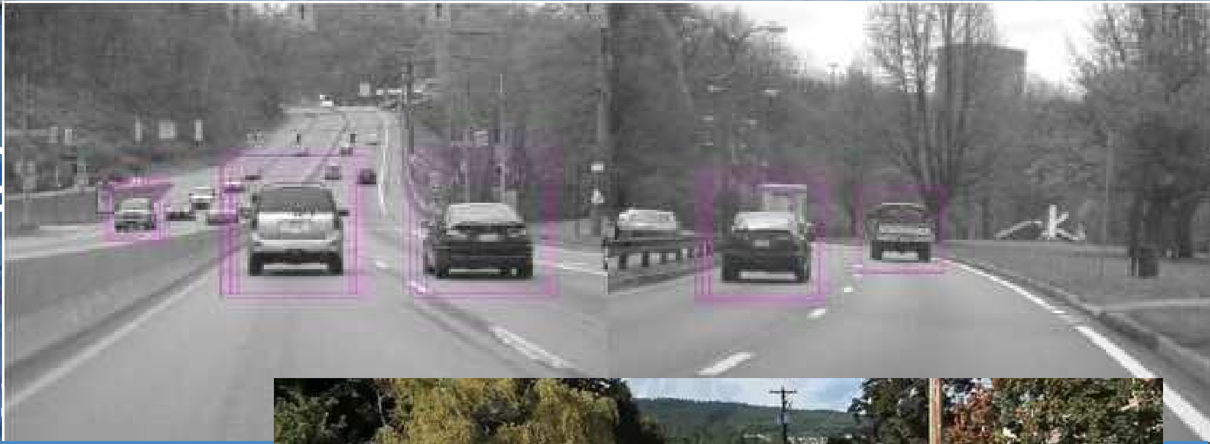


Input image

Three filters selected by AdaBoost

Boosted classifier for car detection

- Larg
- Ada ... ak clas

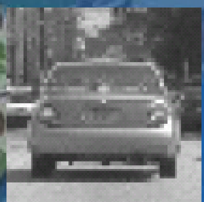


Relatively ... s etection"

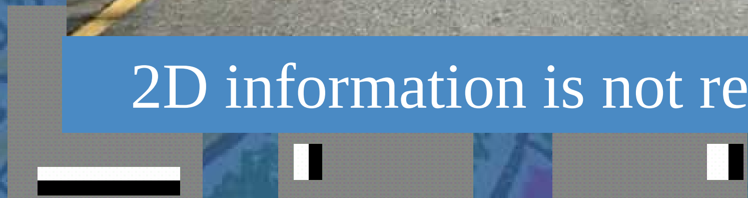
Internatio

2D information is not reliable

David C. Lee, and Ta
"Boosted Classifier fo



Input image



Three filters selected by AdaBoost

Pedestrian detection

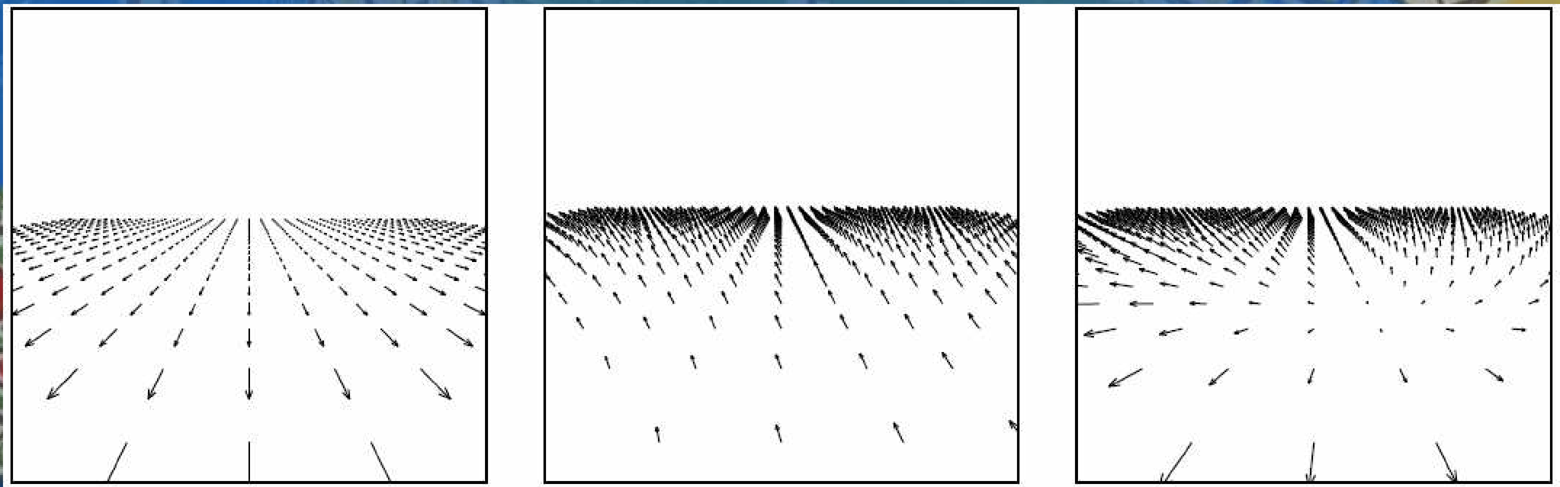
Paper	Approach	Description
Papageorgiou IJCV00[5]	Shape cl	Based on local multiscale oriented intensity differences using Haar wavelet
Abramson IV04 [6]	Sh	
Hashiyama C-SMC03 [7]	M	
Viola ICCV03 [8]	M	
Havasi 04 [9]	Sh	
Shashua 04 [10]	Sh	
Zhao ITS00 [11]	St ne	
Gavrila IV04 [12]	St	
Hilario 05 [13]	Sh	
Gandhi ICIP05 [14]	St	
Lombardi IV04 [15]	Sh he	

Paper	Objective	Sensors	Approach	Description
Broggi IV04 [16]	Detection	FIR	Shape	Detects warm symmetric objects with specific size and ratio at multiple resolutions.
Fang VT04 [17]	Detection	FIR		Shape independent approach using horizontal and vertical projection profiles. Classification based on multi-dimensional histogram, inertia, contrast features.
Meis IV04 [18]	Detection	FIR	Head detection	Statistical approach for pixel classification for head detection. Comparison with classifier for body detection.
Xu ITS05 [19]	Detection, tracking	FIR	Shape	Uses SVM for detection, Kalman filter and mean shift for tracking pedestrians. Output of road-detection module also used for validation.
Liu VT04 [20]	Detection	FIR	Stereo, motion	Detects objects with motion not consistent with background without explicit ego-motion computation. Works well with dominant translation but small rotation of camera.
Tsuji ITS02 [21]	Detection, collision prediction	FIR	Stereo, motion	Design of overall system. Discusses configuration, coordinate systems, simple IR based detection, tracking, computation of relative motion vectors, and conditions for collision judgment.
Fang 03 [22]	Detection comparison	Visible, FIR	Feature-based	Compares use of visible and IR sensors. Introduces multi-dimensional feature-based segmentation and classification. Proposes novel features for segmentation to take advantage of unique properties of IR.
Milch [23]	Detection	RADAR, monocular vision	Time-of-flight, shape	Target-list is generated using RADAR. These are verified by vision using flexible shape models trained from manually extracted pedestrians.
Scheunert IV04 [24]	Tracking	FIR, LASER scanner	Time-of-flight, hot object detection	LASER scanner detection using 1st and 2nd derivatives w.r.t. azimuth angles. IR detection using brightness and orientation. Uses Kalman filter for sensor fusion.

Tarak Gandhi and Mohan M. Trivedi: Pedestrian Collision Avoidance Systems: A Survey of Computer Vision Based Recent Studies, IEEE International Transportation Systems Conf., 2006

Motion Detection

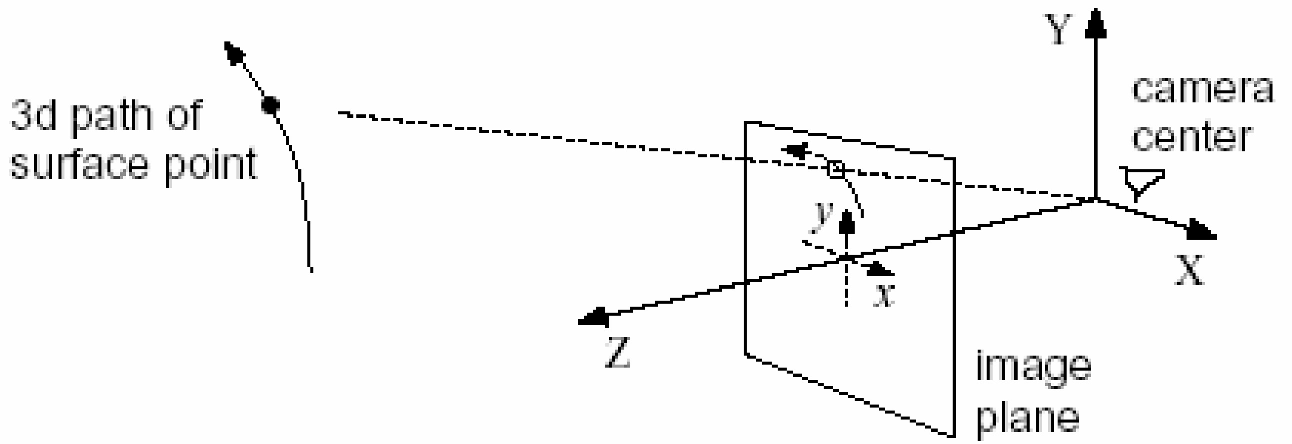
- Find changing areas in videos
- In case of moving cameras everything seems to move
- Motion patterns greatly depend on the camera ego-motion and on the 3D structure of the scene



Translation Rotation Rotation+Translation
of the camera

3D Velocity and 2D Velocity

- Motion equation if the camera moves…
  - **u** ϵ $\mathbf{R}^2$ **:** image motion
  - **T** ϵ $\mathbf{R}^3$: translation of the camera
  - **Ω** ϵ $\mathbf{R}^3$: rotation of the camera



$$\mathbf{u}(x, y) = p(x, y)\mathbf{A}(x, y)\mathbf{T} + \mathbf{B}(x, y)\mathbf{\Omega}$$

$$\mathbf{A}(x, y) = \begin{bmatrix} -f & 0 & x \\ 0 & -f & y \end{bmatrix}$$

$$p(x, y) = 1/Z(x, y)$$

$$\mathbf{B}(x, y) = \begin{bmatrix} (xy)/f & -(f + x^2/f) & y \\ f + y^2/f & -(xy)/f & -x \end{bmatrix}$$

Image velocity in case of plains

- Image points belong to plain objects in 3D space

$$u_h = \frac{1}{fd}(a_1 x^2 + a_2 xy + a_3 fx + a_4 fy + a_5 f^2)$$
$$u_v = \frac{1}{fd}(a_1 xy + a_2 y^2 + a_6 fy + a_7 fx + a_8 f^2).$$

$$a_1 = -d\Omega_y + T_z n_x, \qquad a_2 = d\Omega_x + T_z n_y,$$
$$a_3 = T_z n_z - T_x n_x, \qquad a_4 = d\Omega_z - T_x n_y,$$
$$a_5 = -d\Omega_y - T_x n_z, \qquad a_6 = T_z n_z - T_y n_y$$
$$a_7 = -d\Omega_z - T_y n_x, \qquad a_8 = d\Omega_x - T_y n_z.$$

- The main task is to find, by optimization, the best a_i parameters fitting to observations.

Optical Flow Estimation

- Optical flow is an estimation of motion field
- Optical flow strongly correlates to the projection of real 3D motion
- Calculation is based on intensity conservation:

$$f(x, y, t) = f(x + u_v, y + u_h, t + 1)$$

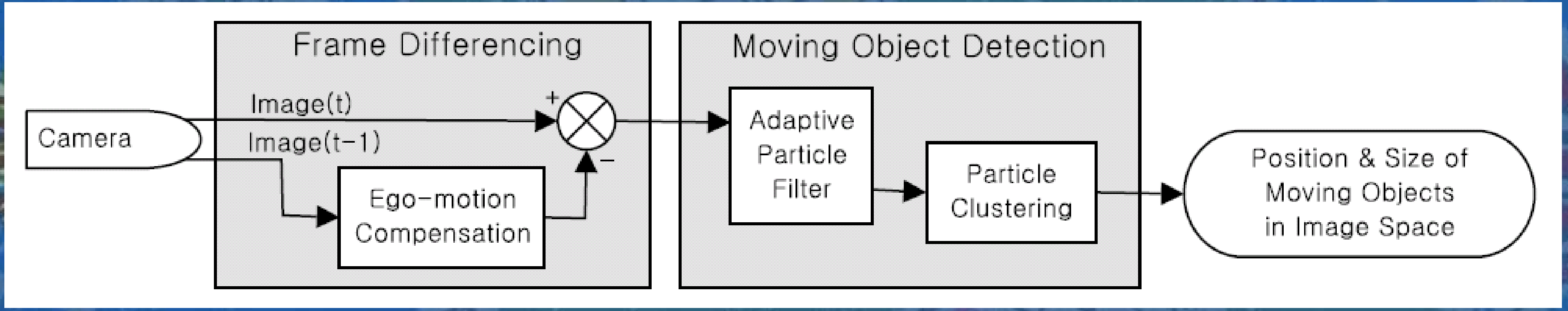
- Several approaches are available:
  - Block matching
  - Horn and Schunk
  - Lucas and Kanade
  - ...

Independent Motion Detection

- It can be done with a single camera
- Assuming majority principle:
  - Some image model is assumed
  - Most points are “normal” background points
  - Outliers belong to independently moving objects (foreground points)

Ego-motion removal

1. Find correspondence of image points in consecutive frames
2. Find the proper transformation between images (affine, perspective or linear models)
3. Apply transformation and make frame differencing

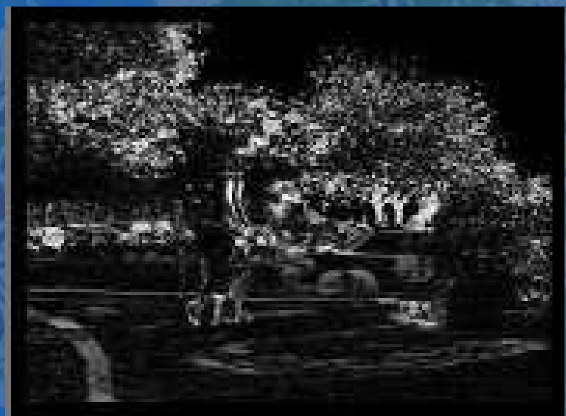


Compensated image difference

Frame t

Frame t+1

Normal difference



Compensated difference

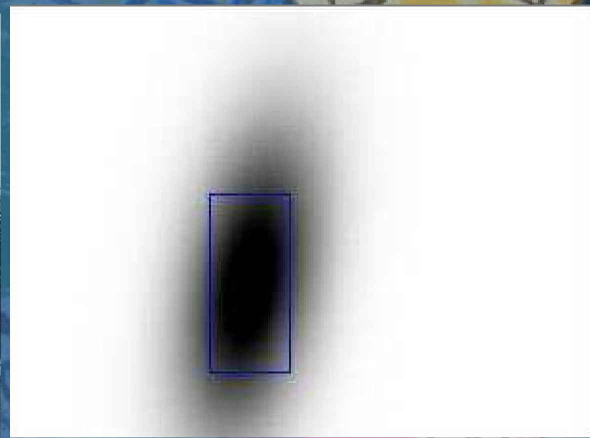
Boyoon Jung and Gaurav S. Sukhatme, Detecting Moving Objects using a Single Camera on a Mobile Robot in an Outdoor Environment, 8th Conf. on Intelligent Autonomous Systems, 2004

Object tracking

- Compensated difference image contains too much noise
- Particle/object tracking applied to find relevant moving points/objects

Input frame

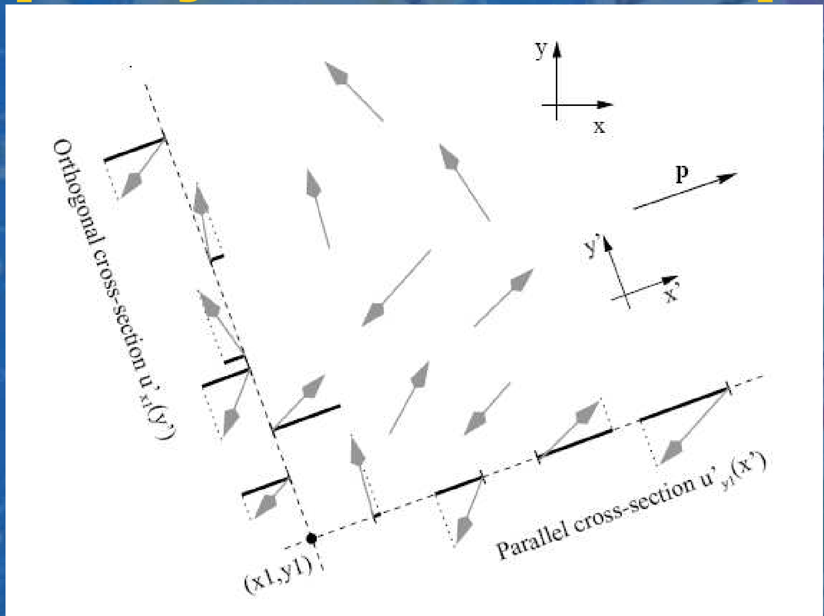
Particles tracked

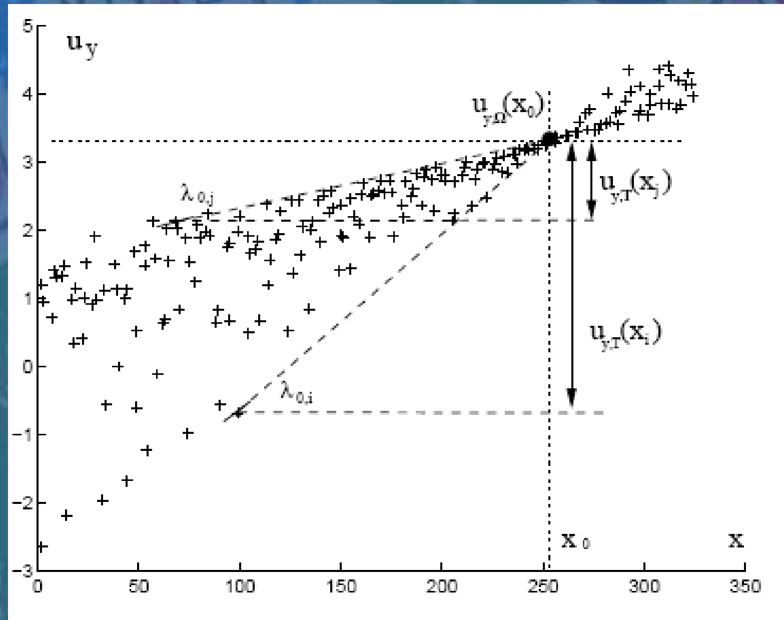


Gaussian fitted

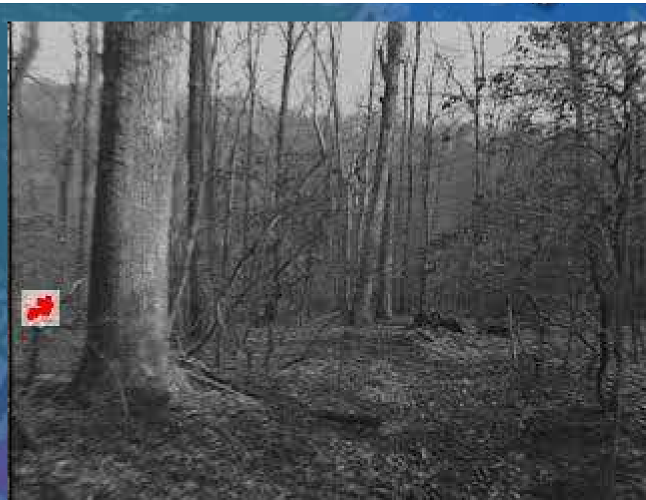
Boyoon Jung and Gaurav S. Sukhatme, Detecting Moving Objects using a Single Camera on a Mobile Robot in an Outdoor Environment, 8th Conf. on Intelligent Autonomous Systems, 2004

Motion detection from the projection of optical flow vectors





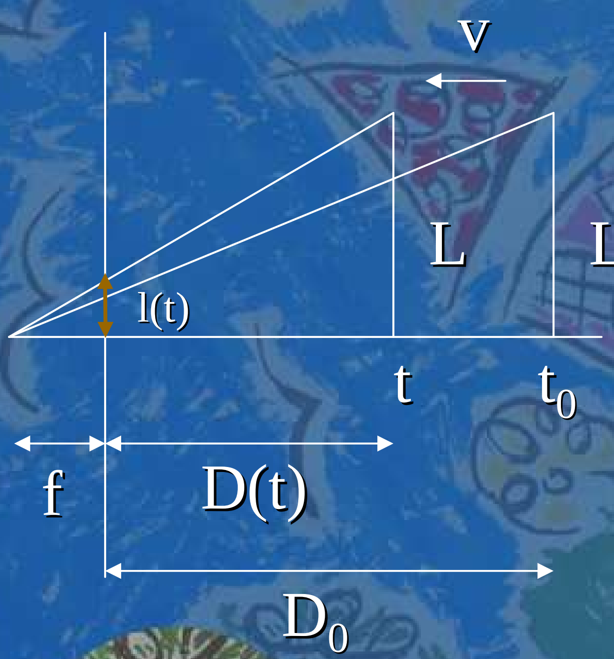
$$\forall x : \begin{cases} x \leq x_0 : & u_y(x) \leq u_{y,\Omega}(x_0) = u_y(x_0) \\ x \geq x_0 : & u_y(x) \geq u_{y,\Omega}(x_0) = u_y(x_0) \end{cases}$$



Drawback: needs large number of vectors

Sándor Fejes and Larry S. Davis: Detection of Independent Motion Using Directional Motion Estimation, Computer Vision and Image Understanding, Volume 74, Issue 2, 1999, Pages 101-120

Simple Collision Detection



- Object of height L moves with constant velocity v
- The image of the object has size l(t)
- It will crash with the camera at time:
  - $D(t) = D_o - vt = 0$
  - Time to Collide: $\tau = D_o/v$

$$l(t) = \frac{fL}{D(t)}$$

$$l'(t) = fL\frac{v}{D^2(t)}$$

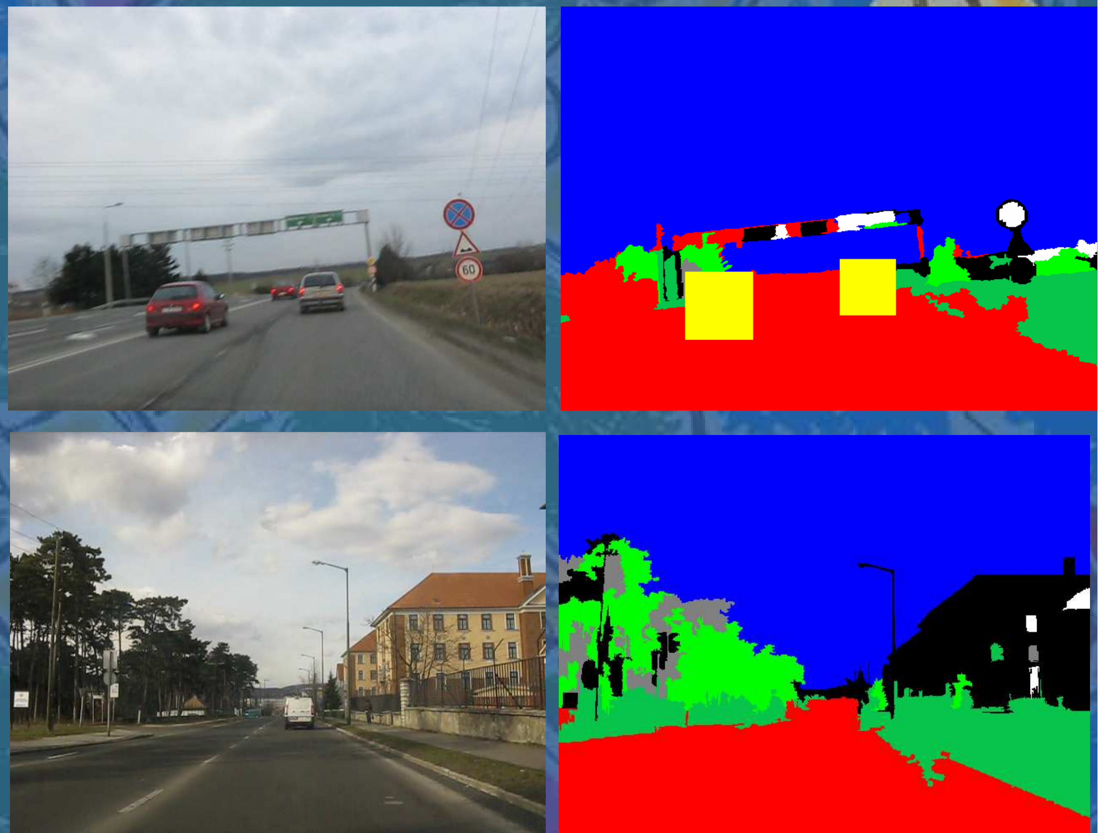
$$\Rightarrow \quad \tau = \frac{l(t)}{l'(t)}$$

But what is the height of objects?
(systems should not warn on patterns of the road surface)

Environment Discovery and Recognition

Image object classification based on segmentation:

1. Oversegmentation of image
2. Generating feature descriptors for image segments
3. Classification of segments



Humans vs. Machines

Driver-vehicle-environment triangle

„The best of both worlds“

Human strengths	Strengths of technical systems
- Flexibility to respond to the situation as required	- No susceptibility to fatigue, stress or distraction
- Rapid decision-making, even in highly complex situations	- Objective measuring and assessment of physical values such as distance and relative speed
- Forward-thinking responses	
- Rapid interpretation of situations	- Fast pre-programmed reactions with high level of precision
- Strongly developed ability to improvise	- Precise and reliable repetition of pre-defined processes
- Instantaneous ethical assessment of situations	

Source: BMW

Potential Problems with DAS

- Complexity of cockpit and handling
- Negative effect on driving skills
- Excessive reliance on ADAS
- Decreasing general driver alertness and systems imperfection can increase risks

Conclusions

- Human errors can be reduced significantly
- Knowledge of human behaviour and psychology is necessary
- Wide diversity of solutions exists
- Intelligent systems: Understanding of complex traffic environment and situation is necessary

Images, graphs and information originate from:

- Urmson, C. et al. Tartan Racing: A Multi-Modal Approach to the DARPA Urban Challenge, *April 13, 2007*
- Sándor Fejes and Larry S. Davis: Detection of Independent Motion Using Directional Motion Estimation, Computer Vision and Image Understanding, Volume 74, Issue 2, 1999, Pages 101-120
- Boyoon Jung and Gaurav S. Sukhatme, Detecting Moving Objects using a Single Camera on a Mobile Robot in an Outdoor Environment, 8th Conf. on Intelligent Autonomous Systems, 2004
- Tarak Gandhi and Mohan M. Trivedi: Pedestrian Collision Avoidance Systems: A Survey of Computer Vision Based Recent Studies, IEEE International Transportation Systems Conf., 2006
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- Karel A. Brookhuis, Dick de Waard and Wiel H. Janssen, Behavioural impacts of Advanced Driver Assistance Systems–an overview, EJTIR, 1, no. 3 (2001), pp. 245 – 253
- Hucker Zsolt, Classification of traffic images, Diploma Thesis, University of Pannonia, 2009

Abstract

- Driver Assistance Systems (DAS) are becoming very popular in today's commercial vehicles. Comfort, safety and environmental considerations require the effective use of a great variety of sensors and signal processing technologies. In the lecture an overview is given about the different DAS applications including the theoretical background of video based systems. Camera-independent motion detection and obstacle detection, as the basis of several functions, are also discussed.