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 pollution 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
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 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).
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**

<table>
<thead>
<tr>
<th></th>
<th>figures</th>
<th>2% (only 2% are faster)</th>
<th>98% (only 2% are slower)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most possible</td>
<td>0.64</td>
<td>0.36</td>
<td>0.78</td>
</tr>
<tr>
<td>Reaction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without view turning</td>
<td>1.12</td>
<td>0.68</td>
<td>1.33</td>
</tr>
<tr>
<td>With view turning &gt; 5°</td>
<td>1.25</td>
<td>0.77</td>
<td>1.48</td>
</tr>
<tr>
<td>Response time</td>
<td>0.05</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>Build-up time</td>
<td>0.17</td>
<td>0.14</td>
<td>0.18</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>2.778</td>
</tr>
<tr>
<td>0.2</td>
<td>5.556</td>
</tr>
<tr>
<td>0.5</td>
<td>13.89</td>
</tr>
<tr>
<td>0.67</td>
<td>18.6</td>
</tr>
<tr>
<td>1</td>
<td>27.78</td>
</tr>
<tr>
<td>1.5</td>
<td>41.67</td>
</tr>
</tbody>
</table>
Example 2: Quality measure for lane departure alert systems

- Beneficial reaction time
- Driver’s reaction time
- Time the driver and car needs for correction
- Car would leave the lane
- DAS warning

Car would leave the lane

Driver’s reaction time
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

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

- **77 GHz Long Range Radar (Lidar)**
  - Far Range: 1 m to ≤120 m

- **Infrared**
  - Night Vision Range: 0 to ≤ 200 m

- **Video**
  - Midrange: 0 to ≤ 80 m

- **24 GHz Short Range Radar**
  - Near Range: 0.2 to ≤ 20 m

- **Ultrasonic**
  - Ultra Near Range: 0.2 to ≤ 1.5 (2.5) m
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:
  \[ X_2 = HX_1 \quad X_1, X_2 \in \mathbb{R}^3 \]

- Using homogeneous coordinates:
  \[ \lambda_1 x_1 = X_1, \quad \lambda_2 x_2 = X_2 \]

- By image coordinates:
  \[ \lambda_2 x_2 = H \lambda_1 x_1 \]

- 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”

David C. Lee and Takeo Kanade.
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" 


Relatively low error late in normal conditions

2D information is not reliable

Input image

Three filters selected by AdaBoost
<table>
<thead>
<tr>
<th>Paper</th>
<th>Approach</th>
<th>Description</th>
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<tr>
<td>Papageorgiou</td>
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<td>Based on local multiscale oriented intensity differences using Haar wavelet.</td>
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<td>DUCV00 [5]</td>
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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...

- $u \in \mathbb{R}^2$: image motion
- $T \in \mathbb{R}^3$: translation of the camera
- $\Omega \in \mathbb{R}^3$: rotation of the camera

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

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

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

$$p(x, y) = 1/Z(x, y)$$
Image velocity in case of plains

- Image points belong to plain objects in 3D space

\[
\begin{align*}
  u_h &= \frac{1}{fd} (a_1 x^2 + a_2 xy + a_3 fx + a_4 fy + a_5 f^2) \\
  u_v &= \frac{1}{fd} (a_1 xy + a_2 y^2 + a_6 fy + a_7 fx + a_8 f^2).
\end{align*}
\]

- 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
Normal difference

Frame t+1
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

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:
  - \( D(t) = D_0 - vt = 0 \)
  - Time to Collide: \( \tau = D_0/v \)

\[ l(t) = fL \frac{D(t)}{D(t)} \]

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

\[ \tau = \frac{l(t)}{l'(t)} \]

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

### „The best of both worlds“

**Human strengths**
- Flexibility to respond to the situation as required
- Rapid decision-making, even in highly complex situations
- Forward-thinking responses
- Rapid interpretation of situations
- Strongly developed ability to improvise
- Instantaneous ethical assessment of situations

**Strengths of technical systems**
- No susceptibility to fatigue, stress or distraction
- Objective measuring and assessment of physical values such as distance and relative speed
- Fast pre-programmed reactions with high level of precision
- Precise and reliable repetition of pre-defined processes

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**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:

- 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
- BMW Group driver assistance systems. BMW Group publications, 2008
- *GLOBAL STATUS REPORT ON ROAD SAFETY*, Department of Violence & Injury Prevention & Disability (VIP), WHO, 2009
- Maria Staubach, Factors correlated with traffic accidents as a basis for evaluating Advanced Driver Assistance Systems, Accident Analysis and Prevention 41 (2009) 1025–1033
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.