Advanced Driver Assistance Systems (ADAS) - Development at Ford Motor Company

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Content

- **Driver Assistance and Active Safety**
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  - Safety Model
  - Attribute
- **Technology Overview**
  - Customer Functions
  - Sensors and Actuators
  - Design Requirements
- **Assessment of Driver Assistance / Active Safety**
- **Control Concept Development**
  - Example „Lane Keeping Aid“
Motivation for ADAS (= Driver Assistance and Active Safety) Technologies

Driver Assistance Technologies
- Customer demand
- Comfort improvement
- Support driver with day-to-day standard tasks

Active Safety Technologies
- Improve real-world safety
- OEM corporate citizenship / responsibility
- Safety rating programs
- Legislation

Most ADAS Systems have a comfort and an active safety portion, e.g. ACC contains cruise control and forward alert
Historical Trends in Total Traffic Accident
Future Product Design

- Population increase
- Aging Population
- Fleet Shift

Future Increase Expected*

Converse trend
Need for advanced safety technologies

* Excludes effect of counter-measures

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What is Active Safety?

Safety model

Phase 1: Normal Driving
Phase 2: Danger Phase
Phase 3: Crash Unavoidable
Phase 4: In Crash
Phase 5: Post Crash

Primary Safety
Secondary Safety
Tertiary Safety

“Active” or “Primary” Safety = Accident avoidance and/or crash severity reduction

Active safety contains the 3 phases of collision avoidance:
- Assistance- (phase 1),
- Warn- (phase 2) and
- Intervene-technologies (phase 2 and phase 3)

can account for collision avoidance
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“Baseline” Driver Assistance Technologies
Ford Focus / 2006

- self-dimming rear view mirror
- heated windscreen
- rain sensing wipers
- auto lighting
- Xenon headlamps
- adaptive front lighting
- hands free phone
- parking sensor
- stable chassis set-up
- ESP
- frost warning
- ABS
- run-flat tires

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Adaptive Cruise Control
ACC

Functional Description
• Driver selects speed and distance level to preceding vehicle
• A sensor will spot preceding vehicles and classify them
• Vehicle automatically adjusts speed and distance respectively time gap by means of the engine and braking systems control
• Forward Alert and Collision Mitigation functionality is included
Electronic Stability Program

Functional Description
ESP improves actively the driving stability
• Acts in all driving maneuvers
• Supports driver in steering maneuvers
• Reduces yaw movement of vehicles

ESP Technical Approach
• Detection of actual driving state
• Detection of driver intention
• Reduction of difference between actual driving state and driver intention by brake interventions at single wheels and engine intervention
Roll Over Mitigation (Part of ESP)

Functional Description

• Reduce the risk of untripped rollover induced by severe steering maneuvers
  • Brake front axle in case of roll over situation to induce understeer tendency

• Reduce the risk of tripped rollover by improving vehicle tracking stability
Semi Automatic Parallel Parking

Functional Description

- During parallel parking the SAPP system does steer the vehicle automatically. The driver just needs to accelerate and brake the vehicle.
- Supports also multiple move manoeuvres so that small park slots can be targeted.
- The Park Slot is measured by Ultrasonic Sensors.
- Only two extra sensors are required to measure the park slot.
Lane Departure Warning

Functional Description

• The lane of the vehicle will be spotted by a camera

• Depending on the system a single lane marker will be sufficient to determine the lane
  • Problem: Perspective depth cannot be recognized (2D) with only one camera: bumpy lane

• In case of driver departing the lane unintentionally, a warning will be generated: audio / haptic / vision

• System in function from a speed level of approx. 70kph and above (subject to tuning)
Comfort Lane Keeping Aid

Functional Goal
• Increase steering comfort on long distance driving
• Reduce number of unintended lane departures

Functional Description
• Continuous and Minimal Steering Torque Assist during normal driving
• Vehicle is kept in lane intuitively at low steering effort
• Useful only on roads with limited curvature and stable lane marking condition

Required System Developments
• Camera with Special Requirements
  - Lateral Offset in Lane
  - Yaw Angle to Lane
  - Curvature of Road ahead
• Simple but sound Control strategy, including camera signal filtering
• New Steering Torque Overlay Controls
• HMI

Key Issues
• Customer Acceptance including HMI
• Driver in the Loop
• How to determine Driver Wish
• Functional Safety
Degree of Driver Assistance

- Manual
- Assisted
- Semi Automatic
- Fully Assisted
- Autonomous

- Lane Departure Warning
- Lane Keeping Aid
- Adaptive Cruise Control
- Semi Automatic Parking
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How to Measure ADAS Technologies?

ADAS Attributes

- Five main classes of attributes are addressed:

  - Lighting
  - Visibility
  - Braking
  - Handling
  - Ergonomics

- Improvements can be judged by reference to real-world accidents - verification by accident data analysis
- Objective design verification of ADAS by means of test procedures is preferred, but typically the driver is “in the loop”
- Driver acceptance is key → customer clinics including measurements of driver behavior and psychological reaction
ESP Objective Testing

Objective evaluation in CAE and in-vehicle

- Example “NHTSA avoidance maneuver”: single sine steer with increasing amplitude (with dwell)
- Open-loop: steering robot
- Assessment of agility and stability in one manoeuvre
- Sideslip angle / yaw rate and lateral acceleration as judgement criteria
Semi Automated Parallel Parking

Objective evaluation in CAE

- Parking scenario definition
- Variation of typical parameters: e.g. start parking position
- Parking result (distance to curb, angle vs. curb) as judgement criteria
VIRTTEX – Driving Simulator
Assessment of driver in the loop

- 24’ Dome
- Hydraulic motion system
- Simulates non-emergency driving

- 180° forward FOV
- 120° rear FOV
- Covers all mirrors
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Comfort Lane Keeping Aid
Control Overview

Driver Torque

Steering System Torque Feedback (+Noise)

Steering Torque

Steering Angle

Vehicle Position in Lane

Driver Wish Estimator

Camera

Vehicle

cLKA Torque Controller

Delta Steering Angle Request

cLKA Angle Controller

Driver Wish Estimator
Comfort Lane Keeping Aid
Steering Angle Controller

Camera Signal

Effective Distance of Camera $D_C$

Wheel Base $WB$

Lateral Displacement $d_Y$

Vehicle Speed $v$

Relative Yaw Angle $d\Phi$

Reference Steering Angle $\delta_R$

Average Radius $r_C$ of Camera Road Shape

Look Ahead Distance $D$

Look Ahead Point

= Positioned on Camera Road Shape at Look Ahead Distance in front of Camera

$\delta_R = \frac{d_Y}{D} + d\phi + WB \cdot \frac{1}{r_C}$
Comfort Lane Keeping Aid
Angle Controller Overview

Performance:
- D
- Driver Wish Evaluator

\[ K_Y = \frac{1}{D} \]
\[ K_\Phi = 1 \]
\[ K_C = WB \]
Comfort Lane Keeping Aid
Quality of Camera Signals

Snake Manoeuvre on straight Road

![Graph showing Yaw Rate and dy vs. Time](image)

plot (time(1:50000), yawrate(1:50000), 'DisplayName','YawRate', 'YDataSource', 'YawRate'); figure(gcf)

Feel the difference

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Comfort Lane Keeping Aid
Quality of Camera Signals

Snake Manoeuvre on straight Road

- Yaw Rate [deg/s]
  - Time [s]
  - Yaw Rate

- dΦ [rad]
  - Time [s]
  - dΦ

plot(time(1:50000), yawrate(1:50000), 'DisplayName','YawRate', 'YDataSource', 'YawRate'); figure(gcf)
Comfort Lane Keeping Aid
Filter Concept

![Diagram showing the flow of data from various sensors to angle controllers.]

- **Curvature Raw**
- **Vehicle Speed**
- **Yaw Rate**
- **dPhi Raw**
- **dPhi Estimator**
- **dy Estimator**

Signals:
- **Camera Signal**
- **ESC Signal**

To Angle Controller

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Feel the difference
Comfort Lane Keeping Aid
Luenberger Observer

\[
x(t) = C + B \int \left( x(t) - q(t) \right)
\]

Estimator
Comfort Lane Keeping Aid
d_{Y} Estimator used for cLKA

\[ \hat{q}(t) = \hat{d}_{Y}(t) \]
\[ x(t) = d_{Y}(t) \]
\[ u(t) = \begin{pmatrix} v(t) \\ d\Phi(t) \end{pmatrix} \text{ from ESC} \]
\[ \dot{d}_{Y} = v \cdot d\Phi \]

\[ \hat{q}(k) = \hat{q}(k-1) \cdot T + \hat{q}(k-1) \]
\[ \dot{\hat{q}}(k) = K \cdot R + v(k) \cdot d\Phi(k), \text{ with } K=1 \]
\[ R = R \left( v(k), d\Phi(k), \hat{d}_{Y}(k) - d_{Y}(k) \right) \]
Residual Checker used for cLKA

\[ \hat{d}_Y(k) = d_Y(k-1) + v_Y(k) + R(k) \cdot T \]

\[ R(k) = \text{sign}(Dif) \cdot \min(|Dif|, L_{max}), \quad L_{max} = \text{const.} \]

\[ Dif(k) = \left( d_Y(k) - d_Y(k-1) \right) / T - v_Y(k) \]
Comfort Lane Keeping Aid

\(d_{\gamma}\) Estimator

Snake Manoeuvre on Straight Road

\(d_y\) [m]

\(d_{\gamma}\) and \(d_{\gamma}\) Estimated

Time [s]
Comfort Lane Keeping Aid

dΦ Estimator used for cLKA

\[ \dot{q}(t) = \hat{d}\phi(t) \]
\[ x(t) = d\phi(t) \]

\[ u(t) = \begin{pmatrix} \dot{\phi}(t) \\ v(t) \end{pmatrix} \]
from ESC
\[ \frac{1}{r_c} \text{ from Camera} \]

\[ d\phi = \text{curv} \cdot v + \dot{\phi} \]

Vehicle Yaw Rate \( \dot{\phi} \)
Average Radius \( r_c \) of Camera Road Shape

Camera Road Shape

Vehicle Speed \( v \)
Relative Yaw Angle \( d\Phi \)

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Comfort Lane Keeping Aid

$\Phi$ Estimator

Snake Manoeuvre on Straight Road

$\Phi$ [rad]

Time [s]
Comfort Lane Keeping Aid

Conclusions

• Simple Controller with feed forward delivers good control results.
• Sensor Signal Filtering is key.
• Safe Environment Sensing and Modelling is a challenge.
• To take the driver in the Loop is a challenge.
• Complex Sensor and Actuator Technologies are getting more and more into mass production.
• Driver Assistance will change the way of driving dramatically and soon.
• How can Control Theory help Driver Assistance in future?
Thank You!

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Back Up ....
\[
\sin(\delta) \approx \delta \approx WB \frac{1}{r}
\]

\[c = \frac{1}{r}\]

\[\delta \approx WB \cdot c\]
Camera Signal

Average Radius $r_C$ of Camera Road Shape

Relative Yaw Angle $d\Phi$

Vehicle Yaw Rate $\phi$

Camera Road Shape

Vehicle Speed $v$