Radar Based Driver Assistance Systems
Radar Based Driver Assistance Systems

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Radar Based Driver Assistance Systems

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  Chassis System Control
  Driver Assistance
  /
  ESA2

Front Radar Platform
Radar Based Driver Assistance Systems

Agenda

- **Driver Assistance Systems**
  - Sensor Data Fusion
  - Basic Terms and Definitions
  - SW Development
  - Radar Basics

- **What can we achieve with a radar sensor?**
  - Adaptive Cruise Control
  - Automatic Emergency Brake
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Agenda
Radar Based Driver Assistance Systems
Use cases addressing end customers needs

Predictive safety
- Predictive emergency braking
- Evasion assistance
- Lane assistance
- Predictive pedestrian protection
- Turn and crossing assistance

Driver comfort & information
- Travel assistance
- Driver monitoring
- Light and sight assistance
- Park and maneuver assistance
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Driver Assistance Systems (DAS)

Definition

- Enhanced safety and driving comfort
- Accident-free driving
- Supports the driver at the best possible rate, especially in critical situations

- **Sensors** survey the surroundings and the interior of the vehicle
- **Control units** monitor and analyze the data of the sensors in real time

Goal:

- **reliable support** with validation by fusion of several sensors to achieve injury, accident free and **comfortable** driving
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Sensor Data Fusion

- Sensor Data Fusion consists of 3 elements:
  - Data fusion
  - Environment Model
  - Situation Interpretation

- Video / Radar / Navigation based joint architecture

<table>
<thead>
<tr>
<th>Camera</th>
<th>Radar</th>
<th>Digital Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane markings</td>
<td>Moving objects</td>
<td>Roadway</td>
</tr>
<tr>
<td>Objects</td>
<td>Stationary objects</td>
<td>Attribute</td>
</tr>
</tbody>
</table>

Fusion
Radar Based Driver Assistance Systems
Basic Terms and Definitions (1)

- **Ground Truth**
  - Observations, identifications of objects to create appropriate representative classes (training sets) for **machine learning** and **algorithm validation**
  - Data is acquired before, during, or after image acquisition
  - Provides the basis for post-processing accuracy assessments
  - Created by manual labeling

- **Key Performance Indicators (KPI)**
  - **Evaluate** the success of an algorithm according to some pre-defined measurable and comparable goal
  - For example: Number of true detections, hourly rate of false detections, reaction time etc.

- **Receiver operating characteristic (ROC) curve**
  - Plots the True Positive Rate against False Positive Rate at various parameter configurations
  - Helps selecting an optimal configuration with respect to costs / benefits

- True Positive: a detection that matches the ground truth (hit)
- True Negative: correct rejection
- False Positive: incorrect detection (false alarm)
- False Negative: incorrect rejection (miss)
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Basic Terms and Definitions (2)

- Automated Evaluation
  - Validation with plenty of recorded measurements
  - Comparison of measurements against Ground Truth
  - Compare the current performance with the previous versions
  - Validate and fulfill the customer criteria

Data Source -> Data Processing -> Evaluation

- Recorded measurements
- Pre-processed data
- Processing Algorithm
- Stat Analysis
- Post-processing
- csv, xls, mat
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What do we want to measure?

- Azimuth, range, [radial velocity]
- Traditionally the RADAR always uses a polar coordinate system
- Equivalent to a Cartesian coordinate system \([r, \Theta] \leftrightarrow [x, y]\)
- We only measure the radial velocity
  - the two components of the velocity vector in a Cartesian coordinate system cannot be reconstructed
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Radar Equation

- The power $P_r$ returning to the receiving antenna is given by the equation:

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R_t^2 R_r^2}$$

- where
  - $P_t =$ transmitter power
  - $G_t = $ gain of the transmitting antenna
  - $A_r = $ effective aperture (area) of the receiving antenna
  - $\sigma = $ radar cross section, or scattering coefficient, of the target
  - $F = $ pattern propagation factor
  - $R_t = $ distance from the transmitter to the target
  - $R_r = $ distance from the target to the receiver.
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Distance Measurement Principle

- We measure the time elapsed between the transmitted pulse and the received echo

\[ t_d = 2 \times \frac{D}{c} \iff D = t_d \times \frac{c}{2} \]
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Radial Velocity Measurement Principle

\[ f_d = \frac{2v_r f_{tx}}{c} \]

- \( f_{tx} \) = is the transmitters frequency
- \( c \) = is the speed of the light
- \( v_r \) = is the radial speed of the aim

We know our transmit frequency, and the frequency we received from this we can measure the speed of the target object!
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FMCW Principle

- So far we have measured the radial speed using the Doppler-effect.
- We can also measure distance in the frequency domain, using the modulation of the transmitted frequency.
- That is what FMCW stands for: Frequency Modulated Continuous Wave.
- For example:

\[ f(t) = f_D + \Delta f \]

\[ f_D(t) = f_D + \Delta f \Delta t \]

http://www.radartutorial.eu
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FMCW Principle

The problem we have to solve is that the two signals we want to measure are „encoded” in the same attribute, the frequency

\[ f_d = \frac{2D}{c} \cdot \frac{\Delta f}{\Delta t} + \frac{2v_r}{\lambda} \]

- \( f_d \): the „measured/received” frequency
- \( D \): distance to the object
- \( \Delta f/\Delta t \): the rate of change of the frequency
- \( v_r \): radial velocity

We have one equation, and two unknown variables => unsolvable problem?
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FMCW Principle

Frequency-Matching: 2 targets, 3 ramps

- Using three ramps, the method is capable of multi-target scenarios
- Using four ramps, ghost targets can be efficiently suppressed
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ACC Stop and Go

Adaptive Cruise Control
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Adaptive Cruise Control

- **Goal**
  - Blue vehicle should always keep a secure distance to the yellow vehicle while keeping the set speed, or the speed of the yellow vehicle

- **Inputs**
  - Radar data
  - Additional video data
  - Ego car data

- **Reaction**
  - Acceleration or deceleration

- **Achieve comfortable driving through automatic longitudinal control**
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Radar points

► Object types
  ► Stationary objects
  ► Dynamic objects

► Road estimation is based on
  ► the connection of stationary objects
  ► the tracking of moving objects
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Radar-Video Fusion

- Use of road markings (lines) from video based driver assistance systems
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Object classification

- Classification of objects in both sensors:
  - Radar classification based on the behavior of the objects
  - Video classification based image features

- Fusion of video based information and radar based information in one system in order to get reliable data
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Parallel lanes

- Yellow vehicle remains the ACC target object because
  - Connection of stationary objects (reflector posts, guardrail)
  - Video line detection and lane recognition
  - Tracking of red and brown vehicle
- indicates how the road ahead looks like
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Automatic Emergency Braking
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Automatic Emergency Breaking

► Goal
  ▶ Fast reaction to avoid collision

► Input
  ▶ Ego Motion
  ▶ Object type classification
  ▶ Motion model for various object types
  ▶ Calculate time to collision
  ▶ Additional information from the driver
    ▶ Driver monitoring to estimate the level of attention

► Reaction
  ▶ Collision avoidance/mitigation with braking/steering

📌 Achieve safe driving through automatic braking
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System Approach

- Data Fusion from different sources (e.g. Radar, Video, Ultrasonic)
  - Objects, line, lane, road signs etc.

- Environmental Hypothesis
  - E.g.: Parallel Lanes, Object-Lane association

- Situation Analysis
  - Criticality of the situation, Driver Activity

- Decision
  - Warning, Partial Braking, Brake Support, Full Emergency Braking
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How to evaluate system performance?

- **System level performance goals:**
  - Reach safety goals
  - High TP rate
  - Low FP rate
  - Efficient code/algorithm

<table>
<thead>
<tr>
<th></th>
<th>Real life event</th>
<th>No event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection/Reaction</td>
<td>TP</td>
<td>FP</td>
</tr>
<tr>
<td>No Detection/Reaction</td>
<td>FN</td>
<td>TN</td>
</tr>
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Thank you for your attention!