INTEGRATION OF A PHENOMENOLOGICAL RADAR SENSOR MODELL IN IPG CARMAKER FOR SIMULATION OF ACC AND AEB SYSTEMS

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OVERVIEW

• Introduction / Motivation

• Description of the Model

• Results

• Conclusion / Outlook
INTRODUCTION / MOTIVATION

• Today Advanced Driver Assistance Systems (ADAS) most times optional equipment

• Euro NCAP will start to include Autonomous Emergency Brake Systems (AEB) and Lane Keeping Systems (LKA) in their star rating

→ ADAS will become standard equipment

• Validation of these systems is done with real test drives which are expensive, time consuming, safety critical, …

→ The validation process can be optimized by using appropriate simulation tools more frequently
METHODS FÜR ADAS VALIDATION

- Prototypes and road trials
- Man-in-the-Loop Testing
  - Driving simulators
- Hardware-in-the-Loop Testing
  - e.g. sensor test benches
- Modelling and simulation

Sources: MAGNA Steyr, IPG, Toyota, FTG
Prototypes and road trials

- Full vehicle required
- Professional test drivers
- Sophisticated measurement equipment
- Test track or public road
- Many testing kilometers
- Reproducibility
- Final proof

Sources: MAGNA Steyr
Example of road based ADAS validation by EURO-NCAP AEB test procedure

Sources: MAGNA Steyr
Sources: MAGNA Steyr
MAN-IN-THE-LOOP: DRIVING SIMULATORS
INVESTIGATION OF HUMAN-SYSTEM INTERACTION, SAFETY, CONFIDENCE AND ACCEPTANCE

Sources: Hochschule Regensburg, Ftronik, FTG, simtec, BMW, Toyota
HIL TEST BENCHES

• Example: HiL test bench for camera validation

Source: IPG
MODELLING AND SIMULATION OF ADAS

- Automatized simulation of maneuvers
- Automatized analysis and report
WHY PHENOMENOLOGICAL MODEL?

- **Physical** radar sensor model
  - A lot of parameters are not available
  - Models are not time efficient
  - Best representation of physical effects in simulations

- **Phenomenological** radar sensor model
  - For concept studies easy parameterization using data sheets
  - Very time efficient simulation
  - Real effects like time delays, signal losses and noisy signals are considered and influence the simulation
MODULES OF THE SENSOR MODEL

- Geometric Model
- Real Sensor Characteristics
- Signal Processing
GEOMETRIC MODEL

- Parameterization FOV
- Coordinate transformation
- Obscuring
- Determination of reference points

$s \varphi_{\text{min},1} < s \varphi_2 < s \varphi_{\text{max},1}$ ➔ Target T2 obscured
REAL SENSOR CHARACTERISTICS

Antenna characteristics

- Approximated with 2\textsuperscript{nd} order polynomial
  
  \[
  SNR(r, \varphi, \sigma) = (a_1 r^2 + a_2 r + a_3) (1 - \text{abs}(b_1 \varphi^2 + b_2 \varphi + b_3)) + \mathcal{N}(0, \sigma^2)
  \]

- Standard deviation depending on position and target type
  
  \[
  \sigma = \varepsilon_0 + r \varepsilon_r + \varphi \varepsilon_\varphi
  \]
REAL SENSOR CHARACTERISTICS

Receiver Characteristics

- Gaussian distribution
- Weather-dependent
- Fixed detection limit

\[ SNR_i \geq SNR_{lim} \Rightarrow \text{Target } i \text{ detected} \]
SIGNAL PROCESSING

Extended Kalman Filter

• Filtering of the raw signal
• Handle short term signal losses

\[
\begin{bmatrix}
    s x_k \\
    s v_{x,k} \\
    s a_{x,k} \\
    s y_k \\
    s v_{y,k} \\
    s a_{y,k}
\end{bmatrix} =
\begin{bmatrix}
    s x_{k-1} + s v_{x,k-1} \Delta t + \frac{1}{2} s a_{x,k-1} \Delta t^2 \\
    s v_{x,k-1} + s a_{x,k-1} \Delta t \\
    s a_{x,k-1} \\
    s y_{k-1} + s v_{y,k-1} \Delta t + \frac{1}{2} s a_{y,k-1} \Delta t^2 \\
    s v_{y,k-1} + s a_{y,k-1} \Delta t \\
    s a_{y,k-1}
\end{bmatrix}
\]

(const. accel. model)

• State-space model

\[
h = \begin{bmatrix}
    \sqrt{s x_k^2 + s y_k^2} \\
    \arctan \left( \frac{s y_k}{s x_k} \right)
\end{bmatrix}
\]

• Nonlinear observation model

\[
Q_k = \begin{bmatrix}
    \sigma_{a_x}^2 & 0 \\
    0 & \sigma_{a_y}^2
\end{bmatrix}, \text{ where } \frac{1}{2} \Delta a_{\text{max},j} \leq \sigma_{a_j} \leq \Delta a_{\text{max},j}
\]
SIGNAL PROCESSING

Path Prediction

- Steady state cornering with low lateral accelerations
  \[ \text{curvature is constant} \]
- Path prediction using the parable approach
  \[ sy = \frac{1}{2} s x^2 \frac{\psi}{v} \]
- Relevant Target if reference point within predicted path
PARAMETRIZATION BY ROAD TRIALS

Object
Object in lane
Object of interest

\[
I = 0.0 \, \text{s} \\
v_{mp} = 0 \, \text{km/h}
\]
MANOEUVRE – DESCRIPTION

- Ego and T1 driving at 130 kph
- T3 – T4 driving at 90 kph
- T2 changes lane within 2.5 s if $s_{r2} < 24 \text{ m}$

- Ego vehicle equipped with AEB
  - Actuation of brakes if $TTC = s_{x}/s_{r} < 0.9 \text{ s}$
  - Building up max. acceleration within 0.5 s
MANOEUVRE – VIDEO

- Transparent vehicle: PHENOMENOLOGICAL sensor model
- Solid vehicle: IDEAL sensor model
MANOEUVRE – RESULTS

Random signal losses

T2 appears in FOV of the phen. model

Delay due to signal processing

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SUMMARY

• Modules of the phenomenological radar sensor model were described.
• Comparison of the simulation results with the phenomenological and an ideal model was shown.
• Significant differences in the outcome of the simulated scenario.

→ The use of the described model generates more realistic results and can improve the development process of new driver assistance systems.
OUTLOOK

- More road trials for enhancement to weather conditions and provision of database for stochastic events such as signal loss
- Enhancement for other sensor principles such as laser
- Enhancement for HiL test benches