Collision Avoidance based on Camera and Radar Fusion

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Agenda

• Motivation
• Perception requirements for collision avoidance
• Situation classification and threat assessment
• Longitudinal and lateral control
• Implementation of collision avoidance in interactIVe test vehicle
• Summary
Evasive Steering in Rear End Collisions, GIDAS Data

- Analysis of the German In-Depth Accident Study, GIDAS indicate, that from all accidents resulting in personal injuries about 10% are frontal collisions of passenger cars against the rear of another vehicle.

Less than one quarter of the following car drivers involved in these accidents tried to avoid the collision by steering.

From accident data obviously no statement can be derived about successfulness of evasion maneuver.
Rear End Collision Avoidance
Accident Scenarios

• Late Reaction - Braking

FV approaches slower LV
FV brakes and hits LV

• Following Distance too low

FV follows LV with unsafe distance
LV needs to brake due to slowing traffic ahead
FV hits LV as could not decelerate in time

• Late Reaction - Steering

FV approaches slower LV
FV steers and hits LV

• No Reaction

1. SV is driving on a straight city street in stop & go traffic

2. LV is braking, SV collides with the rear of LV
Perception Requirements

• Reliable detection and tracking of target (incl. stationary targets)
• Relevant Information about target
  • Distance (<150 m)
  • Relative longitudinal velocity
  • Relative longitudinal acceleration
  • Relative lateral distance
  • Relative lateral velocity
  • Target width
  neither radar only or camera only can provide all information with required accuracy ➔ radar and camera fusion
• Other important information
  • Side objects availability and motion state
  • Road class and geometry
  • Lane information
  • Host vehicle motion state
  • Road friction coefficient
Situation Classification and Threat Assessment

• For each object detected the last point in distance is determined
  • where a rear end collision can be avoided by braking
  • where a rear end collision can be avoided by steering

• The most critical object is the one with the highest last braking / last steering distance

• Determined values can be compared to driver’s last braking / last steering distance from driver study on driver behavior in rear end collision situations (see presentation in T04)
Exemplary Determination of last Steering Distance for a Stationary Target
Examply Determination of last Braking/Steering Distance for a Stationary Target

\[ R^2 = dx^2 + (R - dy)^2 \]
\[ \Rightarrow dx = \sqrt{2Rdy - dy^2} \]
\[ R = \frac{v^2}{a_{\text{max}}} = \frac{v^2}{\mu \cdot g} \]
\[ \Rightarrow dx_{\text{steering}} = \sqrt{2 \frac{v^2}{a_{\text{max}}} dy - dy^2} \]

\[ dx_{\text{braking}} = \frac{v^2}{2a_{\text{max}}} \]
with \[ a_{\text{max}} = \mu \cdot g \]
Longitudinal and Lateral Control

• Once an imminent threat is identified different actions can be considered:
  • Warning the driver
    • Visual warning (e.g. LED bar)
    • Acoustic warning
    • Haptic warning (e.g. force feedback accelerator pedal, brake jerk)
  • Autonomous collision avoidance
    • Automated braking
    • Automated steering

➔ In the following focus is set on autonomous collision avoidance
Flow of Events for autonomous Collision Avoidance

**Road/environment**
- straight road, 2 lanes in the direction of travel

**Lead vehicle (LV)**
- drives at v<60kph
- decelerates:
  - stopped

**Host vehicle (HV)**
- follows LV at v<60kph
- closes in on LV

**RECA**
- detects LV
- braking
- Warning (non-specified)

**HMI**
- Steering wheel
- Brake pedal
- Display
- Speaker
- Hazard lights

**HV driver actions**
- Detects LV
- Brakes
- Heads left
- Passed LV

**Alternative flow 2a**
- straight road, 2 lanes in the direction of travel
- closes in on LV
- decelerates
- stopped without hitting LV
- steers
- Hand over information

**Alternative flow 2b**
- straight road, 2 lanes in the direction of travel
- decelerates
- stopped
- Homologation
- Inattentive
- Attentive

**HV driver states**
- Attentive
- Inattentive
Braking Steering Decision for Stationary Target

Minimum distance to avoid collision

Critical Distance $x_e [m]$ vs. Velocity [kph]

- $x_e$ by steering $\mu=0.2$ (blue)
- $x_e$ by steering $\mu=0.5$ (green)
- $x_e$ by steering $\mu=1.0$ (red)
- $x_e$ by brake $\mu=0.2$ (dashed blue)
- $x_e$ by brake $\mu=0.5$ (dashed green)
- $x_e$ by brake $\mu=1.0$ (dashed red)

Safety factor $k=1$

Break-even-point
Braking Steering Decision

Braking Distance

Steering Distance

Iso distance lines to avoid collision by braking only

Iso distance lines to avoid collision by steering only

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Trajectory Planning

Different types of lane change paths are available with its advantages & disadvantages

- Circular Curve
- Ramp Sinusoid
- Cubic Spirals
- Acceleration Profile
- Single Cartesian Polynomials
- Polar Polynomials
- B-Spline
Trajectory Planning
Trajectory Planning

Single Lane change at 70kph (65kph real)
Reference Generation

Let the polynomial be $\phi(x)$

$$\phi(x) = a_0 + a_1x + a_2x^2 + \ldots + a_5x^5$$

Desired reference signals are required;
1. Yaw rate
2. Yaw Angle
3. Curvature
4. Lateral Acceleration
Control Design

$$\delta = \delta_{FF} + \delta_{FB}$$
Control Design

Feed-forward Loop:

\[ \delta_{FF} = \frac{L}{R} + \frac{m}{l} \left( \frac{l_r}{C_f} - \frac{l_f}{C_r} \right) \frac{V^2}{\rho} \]

Feed-back Loop:

Linear PD controller is designed for yaw rate and yaw angle.

Constraints:

The constraints are as follows

\[ \psi_{\text{start}} = \psi_{\text{end}} = 0 \]
\[ V_{y,\text{start}} = 0 \]
Examplary Simulation Results

Driving conditions:
Vehicle Velocity : 120kph
Road friction : 1.0
Simulation of autonomous Rear End Collision Avoidance

Integrated Collision Avoidance by Brake and Steer

Real Vehicle speed [Kph]

Time [s]

Latitude Acc [m/s²]

Range 255.000 m
Vehicle speed 70.000 m/s
Time Gap 6.000 s
Sensor Configuration in Ford Demonstrator Vehicle
Installed Sensors in Ford Demonstrator Vehicle

Three ESR 76 GHz radars at front:

Two 24 GHz radars at rear:
Installed Sensors in Ford Demonstrator Vehicle

Two cameras at front (Fusion Camera and Delphi):
Autonomous Collision Avoidance with Dummy Target
Thank you.

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