Simulation-based evaluation of the impact of perception sensor configuration on integrated safety of automated vehicle

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Overview of Research

Sensor Set (a front radar)

Sensor specification
(max. Range & Field of View)

Autonomous driving simulations under different sensor sets

Integrated Safety Evaluation

Quantify safety measures

EURO NCAP scenario (CBFA)

Active Safety: Avoiding accidents

Analyze perception capability in terms of area of detection

Passive Safety: Reducing collision impacts

Analyze the impact of sensor’s perception capability with respect to possible collision risk

Evaluate integrated safety considering perception capability and its impact on possible collision risk

Evaluation of the impact of perception sensor configuration on integrated safety
Simulation Process Chain

- Test protocol → Driving simulator
- Scenario configuration
- Simulation output → Scenario Evaluation
- Fatality risk → Simulation software
- Max. Range, Field of View, Velocity of Ego vehicle
**Test protocol: Euro NCAP CBFA**

**Car-to-Bicyclist Farside Adult**

- Axes:
  - AA: Trajectory of bicyclist target crank shaft
  - BB: Axis of controlline of vehicle under test
- Distances:
  - N: Bicyclist target crank shaft, acceleration distance (not within field of view of VU7)
  - O: Bicyclist target crank shaft, steady state distance to 50% impact
- Points:
  - Q: Impact position for 50% farside scenarios

*Figure 7-9: CBFA scenario, Bicyclist from Farside*

**Generate a simulation scenario within the simulator**

Simulator setup (Ansos Driving Simulator)

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Simulation Process Chain

Scenario configuration → Max. Range, Field of View, Velocity of Ego vehicle

Test protocol → Driving simulator

Simulation output → Scenario Evaluation

Fatality risk → Simulation software

When target is detected by a sensor, ego-vehicle decelerates to max. deceleration

Max. Range
FoV
Velocity
Ego vehicle

Bicyclist (Target)
Simulation Process Chain

Scenario configuration → Max. Range, Field of View, Velocity of Ego vehicle

Test protocol → Driving simulator → Simulation output → Scenario Evaluation

Simulation software

Collision occurred
Then, ‘Impact speed’ is recorded
Simulation Process Chain

- **Scenario configuration**
  - Max. Range, Field of View, Velocity of Ego vehicle

- **Test protocol**
  - **Driving simulator**
  - Simulation output
  - **Scenario Evaluation**
  - Fatality risk
  - **Simulation software**

- **Operation Scenario (i.e. NCAP)**
  - Ego-Vehicle
  - Max. Deceleration
  - Initial velocity before stopping
  - Minimum stopping distance

- **Sensor set**
  - Max. FOV & range of detection
  - Max. detection distance

- **Fatality risk**
  - Passive safety
  - Active safety

- **Fatality risk as a function of impact speed**
  - [D.C. Richards, 2010]

\[
\text{Fatality risk} = \frac{1}{1 + e^{6.9 - 0.090 \times \text{Impact speed}}}
\]

Simulation results & an example use-case
Simulation results: fatality risk for different sensor configurations

- **No collision (fatality risk=0)**
- **Collision occurred (fatality risk>0)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Range</td>
<td>(30m, 150m)</td>
</tr>
<tr>
<td>Field of View</td>
<td>(10°, 80°)</td>
</tr>
<tr>
<td>Velocity (Ego Veh.)</td>
<td>(40km/h, 100km/h)</td>
</tr>
<tr>
<td># of simulations</td>
<td>800</td>
</tr>
</tbody>
</table>
Safety requirement for a front radar

- No collision (fatality risk=0)
- Collision occurred (fatality risk>0)

Fault-tree of an automated vehicle operation

Safety risk requirement=0.05 (as an example)
Sensor configuration in terms of integrated safety
- Allowable sensor configurations given the safety requirement

Safety requirement: Fatality risk < 0.05

Points that satisfy the safety requirement

Wider detection coverage of a sensor

Beyond the range of the simulation

5 Velocity: 40 - 50 km/h  
7 Velocity: 50 - 70 km/h  
9 Velocity: 70 - 90 km/h
Sensor configuration in terms of integrated safety
- Typical types of radar sensors

Safety requirement: Fatality risk < 0.05

<table>
<thead>
<tr>
<th>Field of View (°)</th>
<th>Max. Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-range radar</td>
<td>55 m, 80°</td>
</tr>
<tr>
<td>Mid-range radar</td>
<td>60 m, 60°</td>
</tr>
<tr>
<td>Long-range radar</td>
<td>150 m, 20°</td>
</tr>
</tbody>
</table>

Beyond the range of the simulation

5  Velocity: 40 - 50 km/h  
7  Velocity: 50 - 70 km/h  
9  Velocity: 70 - 90 km/h
Sensor configuration in terms of integrated safety
- With a single radar

Using a single radar (regardless of radar type), the safety requirement (fatality risk < 0.05) is met when ego-vehicle velocity is less than 50 km/h.

**Safety requirement: Fatality risk < 0.05**

### Field of View (°)
- **Short-range radar**
- **Mid-range radar**
- **Long-range radar**

### Max. Range (m)
- **5** Velocity: 40 - 50 km/h
- **7** Velocity: 50 - 70 km/h
- **9** Velocity: 70 - 90 km/h

Beyond the range of the simulation
Sensor configuration in terms of integrated safety
- Direction for supplementing sensor configuration to meet the safety requirement

To meet the safety requirement from a vehicle with velocity greater than 50 km/h,

more than one long-range radars can be considered to obtain wider FOV
Sensor configuration in terms of integrated safety
- Direction for supplementing sensor configuration to meet the safety requirement

**Safety requirement: Fatality risk < 0.05**

To meet the safety requirement from a vehicle with velocity greater than 50 km/h, more than one long-range radars can be considered to obtain wider FOV.

**Conclusion**

This study can be used to provide criteria for equipping sensors in automated vehicles to ensure a high level of integrated safety.
Thank you
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