Robust Design of Sensors and Functions in Vehicular Safety

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Motivation

- sensors:
  - measure quantities like distances, velocities, accelerations, etc.
  - serve perception of environment of vehicle
- (vehicular safety) function:
  - uses measurements of sensors
  - interprets driving situation
  - triggers actions in dangerous situations like automatic emergency braking (AEB)
- problem: measurements of sensors are erroneous
- goal: function meets customer requirements in a robust manner despite measurement errors

Problem Formulation

- How must function be designed such that it meets customer requirements in a robust manner despite measurement errors of given sensors?
- Which requirements must sensors meet such that given function meets customer requirements in a robust manner despite their measurement errors?

Mathematical Model for Design of AEB System

- state: $x[n] = [x_0[n] \cdots x_m[n]]$
- measurement: $y[n] = [y_0[n] \cdots y_m[n]]$
- obtained by sensors with sampling rate $s$ at $t_n = nT_s$, $n \in \mathbb{N}_0$
- measured distance: $y_0[n] = x_0[n] + e_0[n]$, i.i.d. $e_0[n] \sim \mathcal{N}(0, \sigma_0^2)$
- measured relative velocity: $y_1[n] = y_0[n]$
- predicted time-to-collision (TTC): $\tau_{\text{TTC}}[n] = -\frac{y_1[n]}{a[n]}

- AEB intervention
  - triggered by function at time instant $t_n$ if $\tau_{\text{TTC}}[n] \leq r$ with threshold $r$
  - reduces velocity of ego vehicle with constant deceleration $a$

Joint Function and Sensor Design for AEB System

$$f_{\text{opt}} = \arg \max_{\sigma \in \mathbb{R}^n_{+}} \text{subject to } P(f_{\text{min}} \leq x_{\text{end}} \leq f_{\text{max}}) \geq 

\text{probability that distance $x_{\text{end}}$ from object after AEB intervention when relative velocity vanishes lies in acceptable interval $[f_{\text{min}}, f_{\text{max}}]$ (quality measure)}

- $f_{\text{min}}$: required minimum probability for fulfilling specification $x_{\text{end}} \leq f_{\text{max}}$
- $f_{\text{max}}$: maximal tolerable standard deviation of sensor measurement errors
- $f_{\text{opt}}$: optimal threshold of function

Conclusion

- new methodology for robust design of AEB system considering sensor measurement errors
- future work: transfer of developed design methodology to further vehicular safety systems

References