NRI: Receding Horizon Integrity-A New Navigation Safety Methodology for Co-Robotic Passenger Vehicles

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We can evaluate the impact of undetected sensor faults on robot localization safety

Key Challenges

- Evaluate and guarantee localization integrity, a measure of trust in sensor information, valid even in the presence of undetected faults
- Used in aviation for decades (proven safety record)
- Quantifiable, sensor- and platform-independent

• Safety risk ≡ risk of Hazardous Misleading Information (*HMI*):

$$HMI_k \equiv \left\{ \boldsymbol{\alpha}^T \hat{\boldsymbol{\epsilon}}_k > \ell \right\} \cap \left\{ q_D < T_D \right\}$$

Time; Selects state of interest; Pose error; Specified *alert limit* defines acceptability on error; Detector; Specified *detector threshold*

• Evaluated under fault-free and faulted conditions:

$$P\left(HMI_k\right) = \underbrace{P\left(HMI_k, NF\right)}_{\text{Probability of HMI and having no faults}} + \underbrace{P\left(HMI_k, F\right)}_{\text{Probability of HMI and having at least one fault}}$$

• Impossible to solve $P(HMI)$, therefore upper bound:

$$P\left(HMI\right) \leq \breve{P}\left(HMI\right) \leq \underbrace{I_{REQ}}_{\text{A predefined integrity risk requirement}}$$

Calculated using estimate error variance

$$P\left(HMI_k\right) \leq 1 + \left(P\left(HMI_k | CA_K\right) - 1\right) P\left(CA_K\right)$$

Probability of a correct association

In this portion of the work, we account for missassociations in the data association process between extracted features and landmarks on a map (e.g. feature A gets associated with landmark B and feature B gets associated with landmark A).

Bound on the probability that the lower bound on the separation between landmarks is larger than the actual separation

Accounts for the separation among landmarks - more separation increases $P(CA)$

$$P\left(CA_K | CA_{K-1}\right) \geq 1 - n_{FoV} + \left(1 - \frac{I_y}{n_{FoV}}\right) \sum_{l=1}^{n_{FoV}} \chi^2_{m+m_F} \left[\frac{1}{4} \left\| \mathbf{y}_l^* \right\|^2_{\mathbf{Y}_{i_l}^{-1}}\right]$$

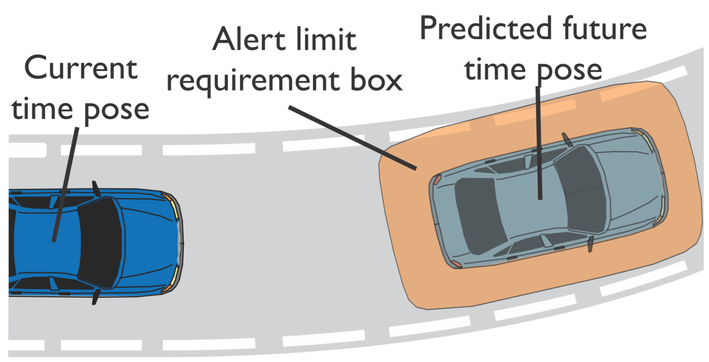
Number of landmarks in the field of view - more landmarks decreases the probability of correct association

More landmarks increases $P(CA)$

Chi-squared distribution emerges from the Gaussian sensor and Kalman filter noise

Scientific Impact

- Establish high-integrity sensor measurement error and fault models for non-GPS sensors
- Develop analytical methods to quantify the safety risk of feature extraction and data association algorithms required in lidar, radar, and camera-based localization
- Design multi-sensor pose estimators and integrity monitors to evaluate the impact of undetected sensor faults on safety risk
- Derive, analyze, and experimentally implement integrity risk prediction in dynamic environments



Societal Impact

- Reduce accident rate, congestion, and emissions
- Current, experimental approaches to prove safety rely on billions of miles driven and require experiments to restart whenever significant changes in sensors or algorithms occur
- In contrast, our approach leverages analytical methods used in aviation safety

Broader Impact – Education and Outreach

- Localization safety analytical tools have been used by the School of Architecture
- Outreach at Chicago's Museum of Science and Industry

Create a mathematically rigorous method to evaluate co-robot navigation integrity

- Identifies unsafe conditions
- Creates metric to compare and evaluate safety across manufacturers
- Provides regulating agencies clear metrics for certification

Reduces time to operational capability

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