RECEDING HORIZON INTEGRITY: A NEW NAVIGATION SAFETY METHODOLOGY FOR CO-ROBOTIC PASSENGER VEHICLES

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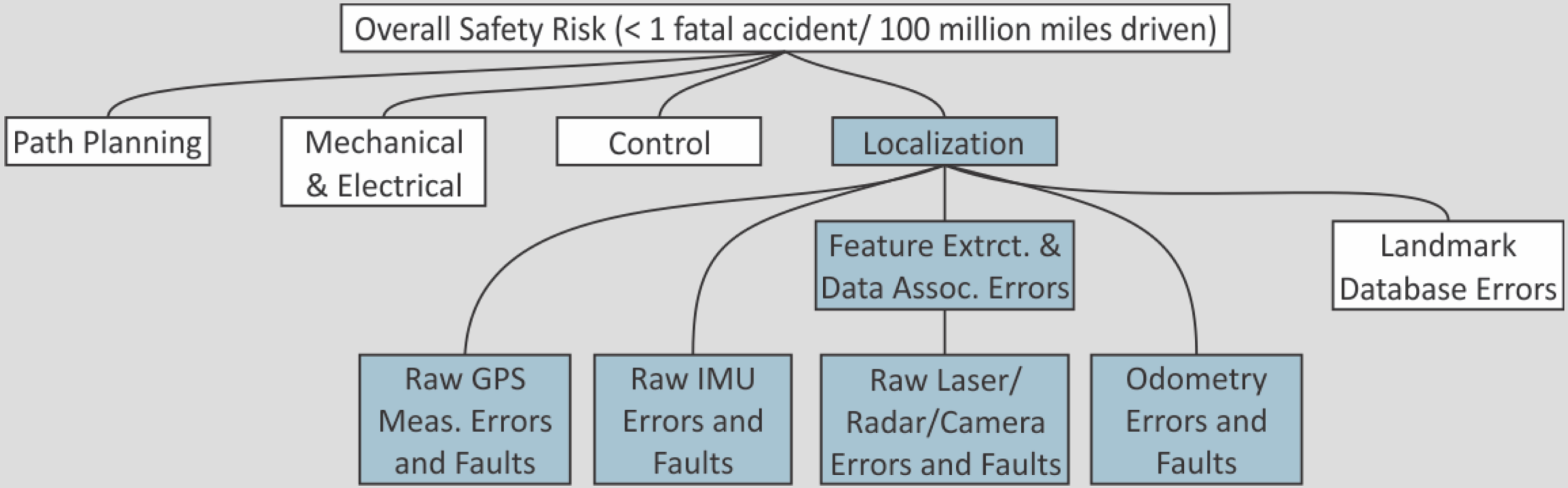
MOBILE CO-ROBOT SAFETY



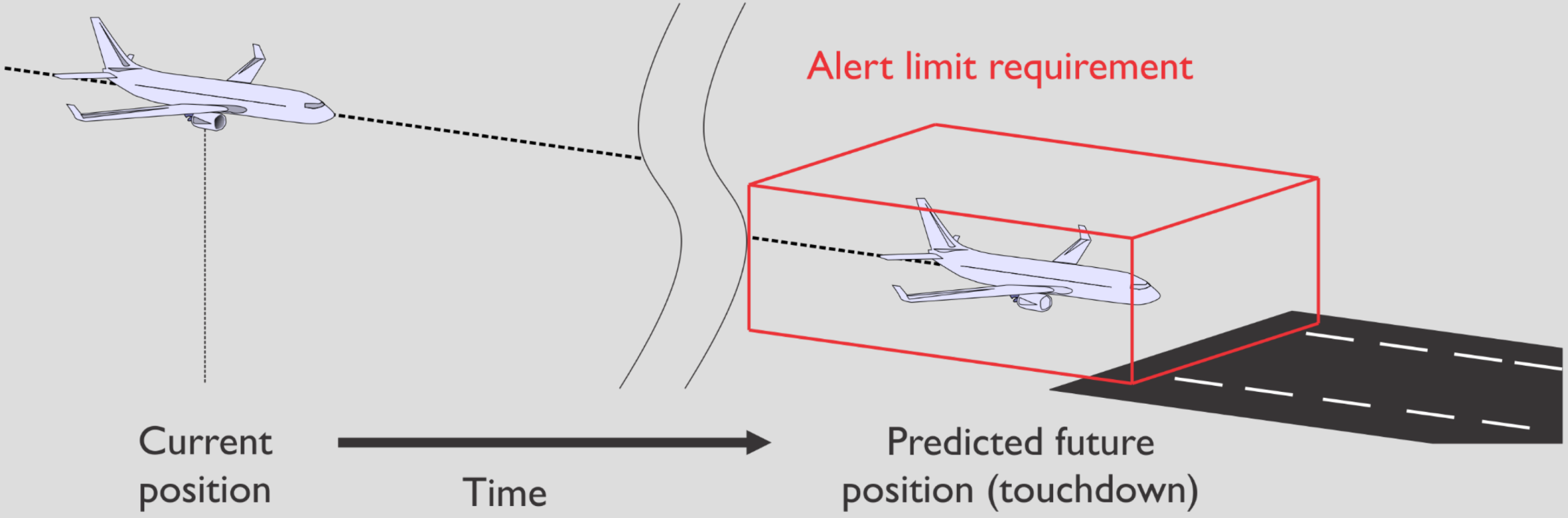
CAN WE PROVE IT EXPERIMENTALLY?

How many miles would have to be driven without failure to demonstrate with 95% confidence that the failure rate is … [Kalra, 2016]	Miles
less than current	275 million
20% better than current	11 billion

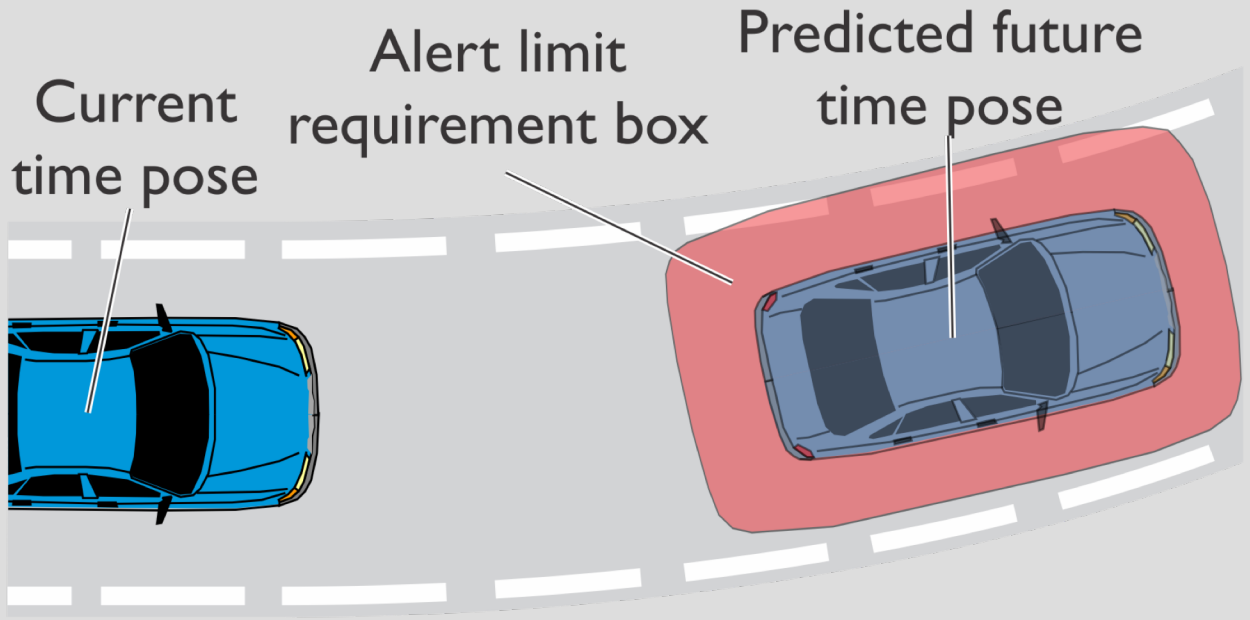
- In aviation applications, safety is guaranteed by monitoring integrity, an analytical measure of trust in a sensor's information

[Kalra, 2016] – Kalra and Paddock "Driving to Safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability" Rand Corporation, 2016

ANALYTICAL METHODS USED IN AVIATION



CHALLENGES IN ADOPTING AVIATION SAFETY METHODS TO MOBILE ROBOTS

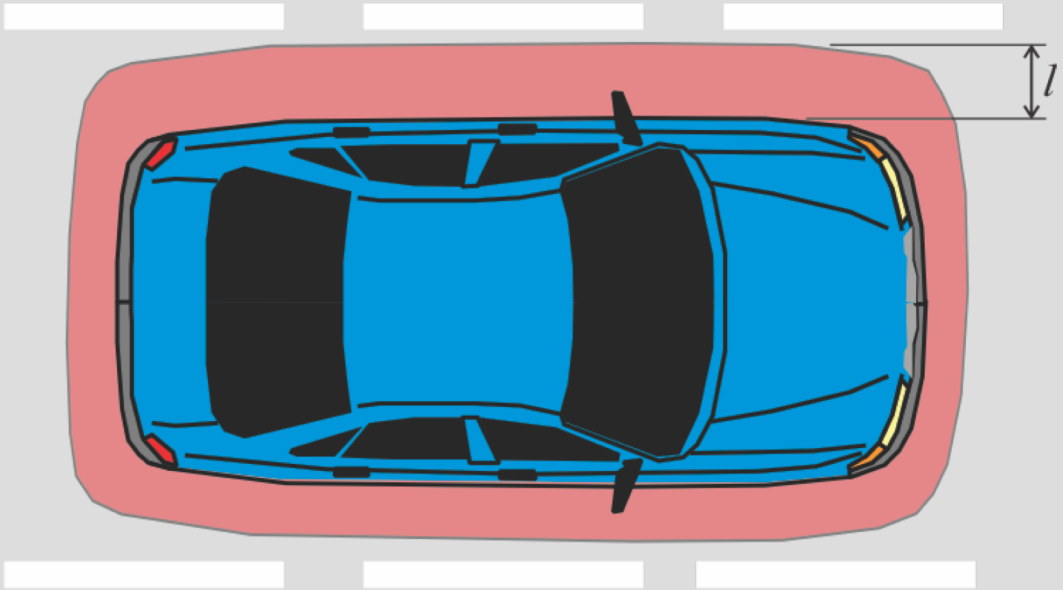


Challenge	Need
GNSS-alone is insufficient	Multi-sensor system
Not only peak in safety risk at landing	Continuous risk monitoring
Unpredictable measurement availability	Prediction in dynamic environment

INTEGRITY RISK

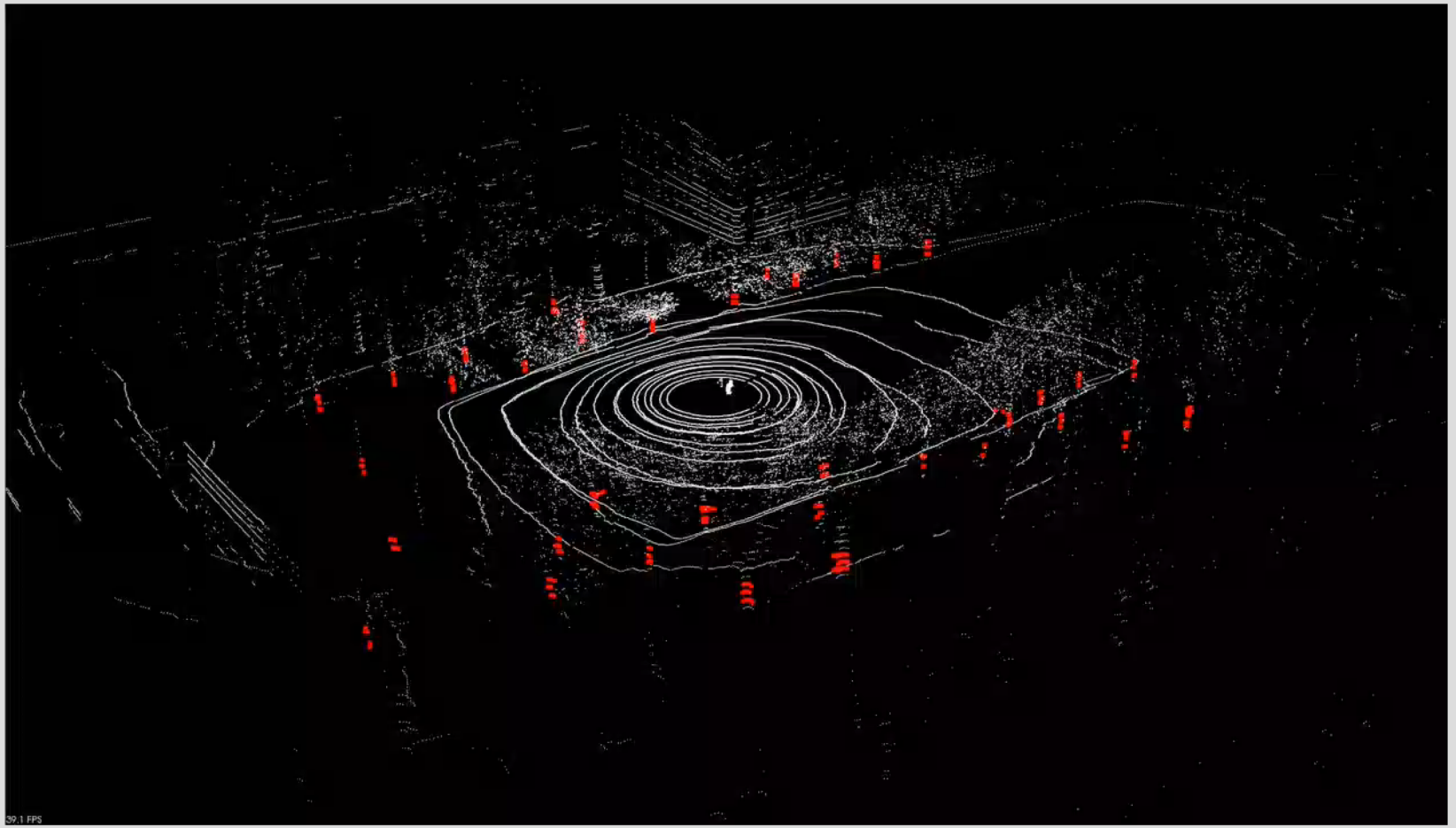
- Localization integrity risk is evaluated as the probability of *Hazardous Misleading Information* (HMI)
- Occurs when *undetected* faults produce an estimate error beyond some predefined limit:

$$\underbrace{HMI_k}_{\text{Hazardous misleading information at time } k} \equiv \underbrace{\hat{\epsilon}_k}_{\text{Pose estimate error at time k}} > \underbrace{l}_{\text{Alert limit}} \bigcap \underbrace{q_k}_{\text{The detector, the difference between sensor readings and what we expect from the system model}} < \underbrace{T}_{\text{Predefined threshold}}$$



FEATURE EXTRACTION AND DATA ASSOCIATION

Extracted features (trees) in red



Feature extractions from experimental data

DATA ASSOCIATION

- Landmarks faults
  - Feature faults – landmark is associated to a wrongly extracted feature
  - Misassociation – a landmark is associated with a feature correctly extracted from a different landmark

Obscured posts because of construction could cause a possible *feature fault*

Landmarks too close together could cause a *misassociation*

PROBABILITY OF HAZARDOUS MISLEADING INFORMATION
$P(HMI)$

- Evaluated under fault-free, or correctly associated (CA) and faulted, or incorrectly associated (IA) conditions:
- Impossible to evaluate exactly, instead bound as:

$$P(HMI_k) \leq 1 + (P(HMI_k|CA_k) - 1)P(CA_k) \equiv \breve{P}(HMI_k)$$

Solvable from covariance of Kalman filter update

??

Upper bound must meet safety requirements set by regulating agency

BOUDNING $P(CA_k)$

$$P(HMI_k) \leq 1 + (P(HMI_k|CA_k) - 1)P(CA_k)$$

More landmarks = lower P(HMI)

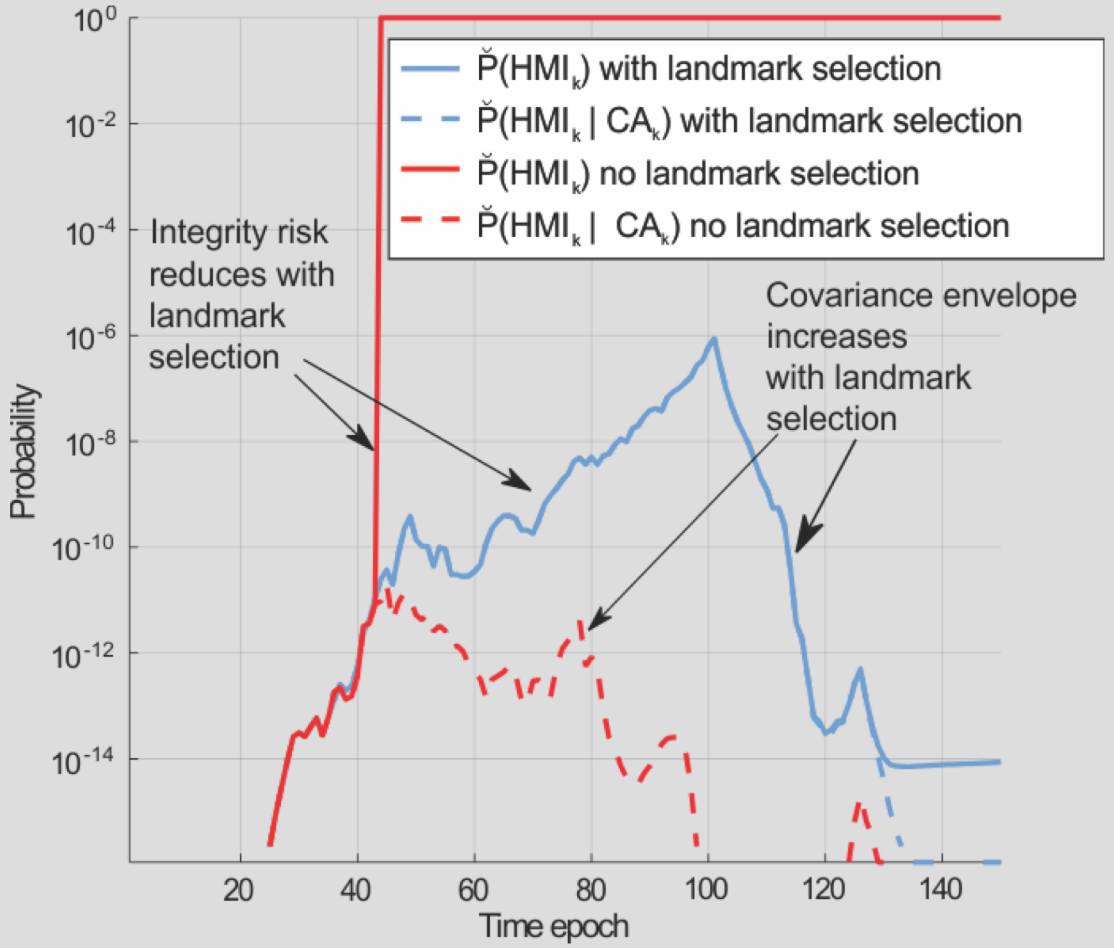
$$P(CA_k) > 1 - n_{FoV} + \left(1 - \frac{I_y}{n_{FoV}}\right) \sum_{l=1}^{n_{FoV}} \chi^2_{m+m_F} \left[\frac{1}{4} \|\mathbf{y}_l^*\|^2_{\mathbf{Y}_{i_l}^{-1}}\right]$$

Number of landmarks in the field of view. More landmarks = higher P(HMI)

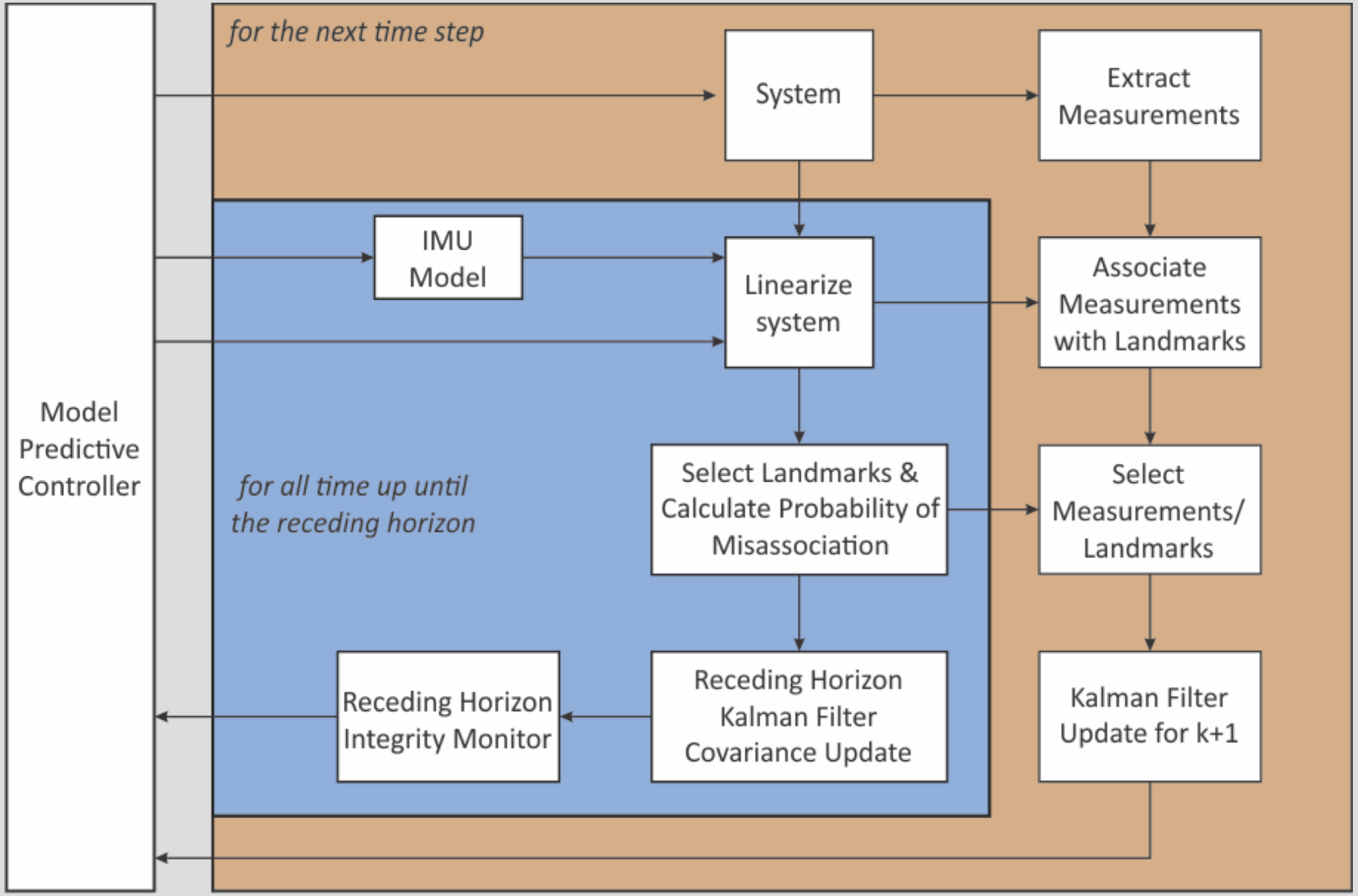
Accounts for the separation among landmarks. More separation equates = lower P(HMI)

LANDMARK SELECTION

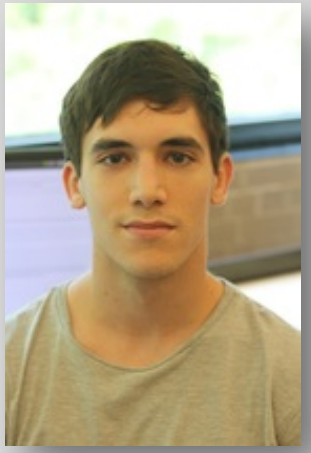
Simulation environment



PUTTING IT ALL TOGETHER



ACKNOWLEDGMENTS



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