Integrity Management of Payload Systems in Autonomous Vehicles

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Agenda

- Background
- Examples
  - Camera (Electro-optical) and Radar
- Integrity management architecture
- System wide integrity
- Conclusion and future work

Background

Objective: Enable safe integration of information from non-critical data sources into critical decision making systems

Mission critical systems
- Sensor payload

→ Integrity management →

Safety critical systems
- Flight control system
- Vehicle management

- Non-redundant
- Failures are tolerable
- Feed data into critical decision making systems

- Can be redundant
- Failures are very expensive

Camera / Radar / Ladar ⇒ Integrity management ⇒ Collision detection ⇒ Avoidance (guidance)

Applications:

Collision avoidance, Intelligence Surveillance and Reconnaissance (ISR), Terrain following

Integrity of camera data

Questions

1. Is the data good enough for obstacle avoidance or target detection?
2. What is the reason for saturation?
3. Does the saturation affect the performance of the system?
4. Can it be mitigated or averted?

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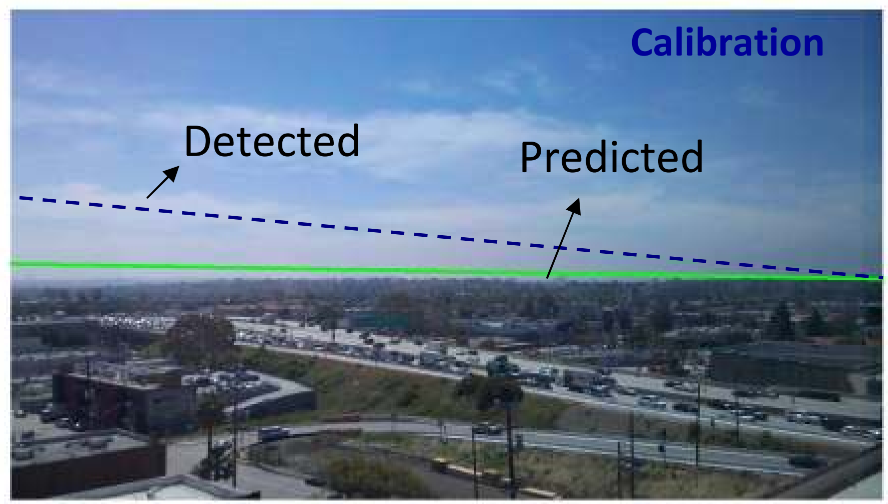
Example: Image Integrity



Example: Image integrity problems

- Pixel saturation
  - Detection based on pixel intensity (reasonableness check)
- Pixel defects
  - Detection based on rate of change of pixel intensity (trend analysis)
- Calibration errors
  - Exploit windows of opportunity
    - Sun charts, intruders, clouds,…
- Degraded visibility/image quality
  - Detection based on external information (e.g. local weather) and overall image intensity/texture content

Example: Radar integrity

$$\tilde{r} = r + r_b + \delta g\, r + \upsilon_r$$

Measured range ($\tilde{r}$), True range (r), Range bias (r_b), Radar gain error (δg), Measurement noise (υ_r)

- Range bias (r_b)
  - Detection based on analytical redundancy between EO bearing and radar range (EKF Filter based/analytical redundancy)
- Range bias in presence of gain error (δg)
  - Detection based on analytical redundancy between EO bearing and radar range (EKF filter based/analytical redundancy)
- Radar bearing error
  - Detection based on comparison with EO bearing measurements (dissimilar redundancy)
- Degraded radar signal due to weather/terrain
  - Detection based on external information (local weather/terrain) and increased clutter

Example: Radar bias

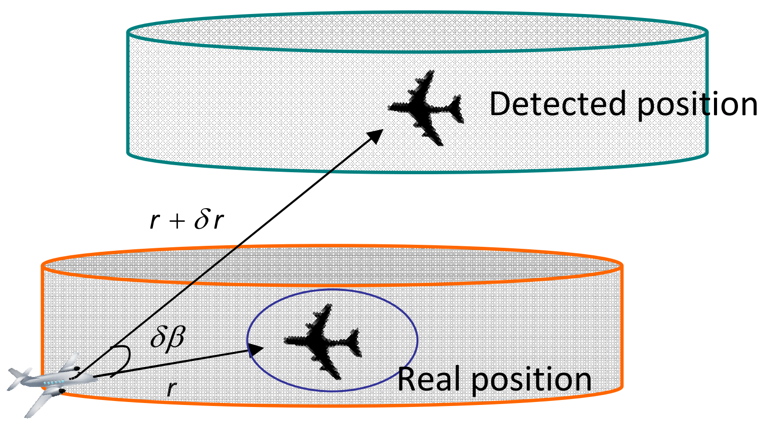
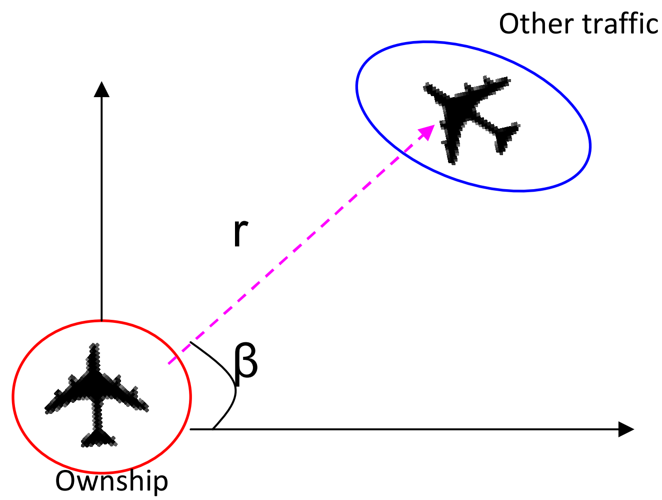
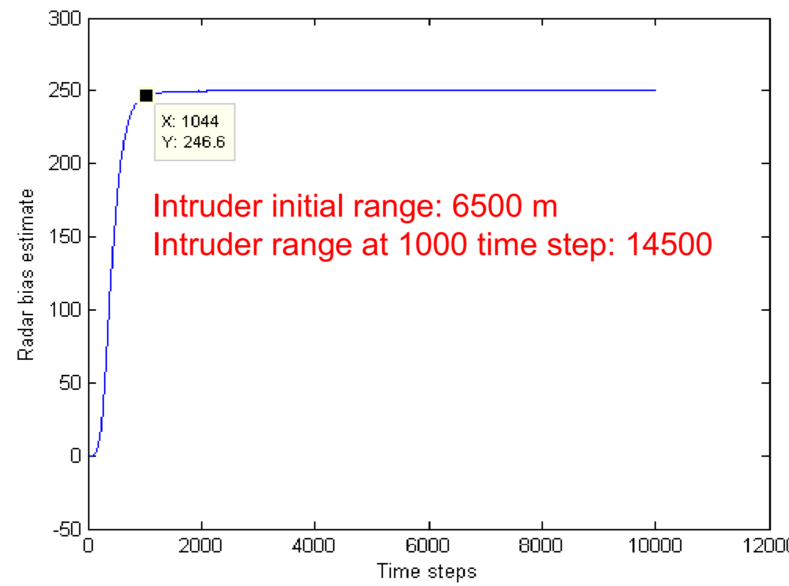


Illustration of a missed detection due to bias in range and bearing angle

- Exploit analytical redundancy between radar and EO (camera) to compute radar bias
- Raise an alarm if bias exceeds critical threshold





Estimated bias versus time

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Integrity management: Desired characteristics

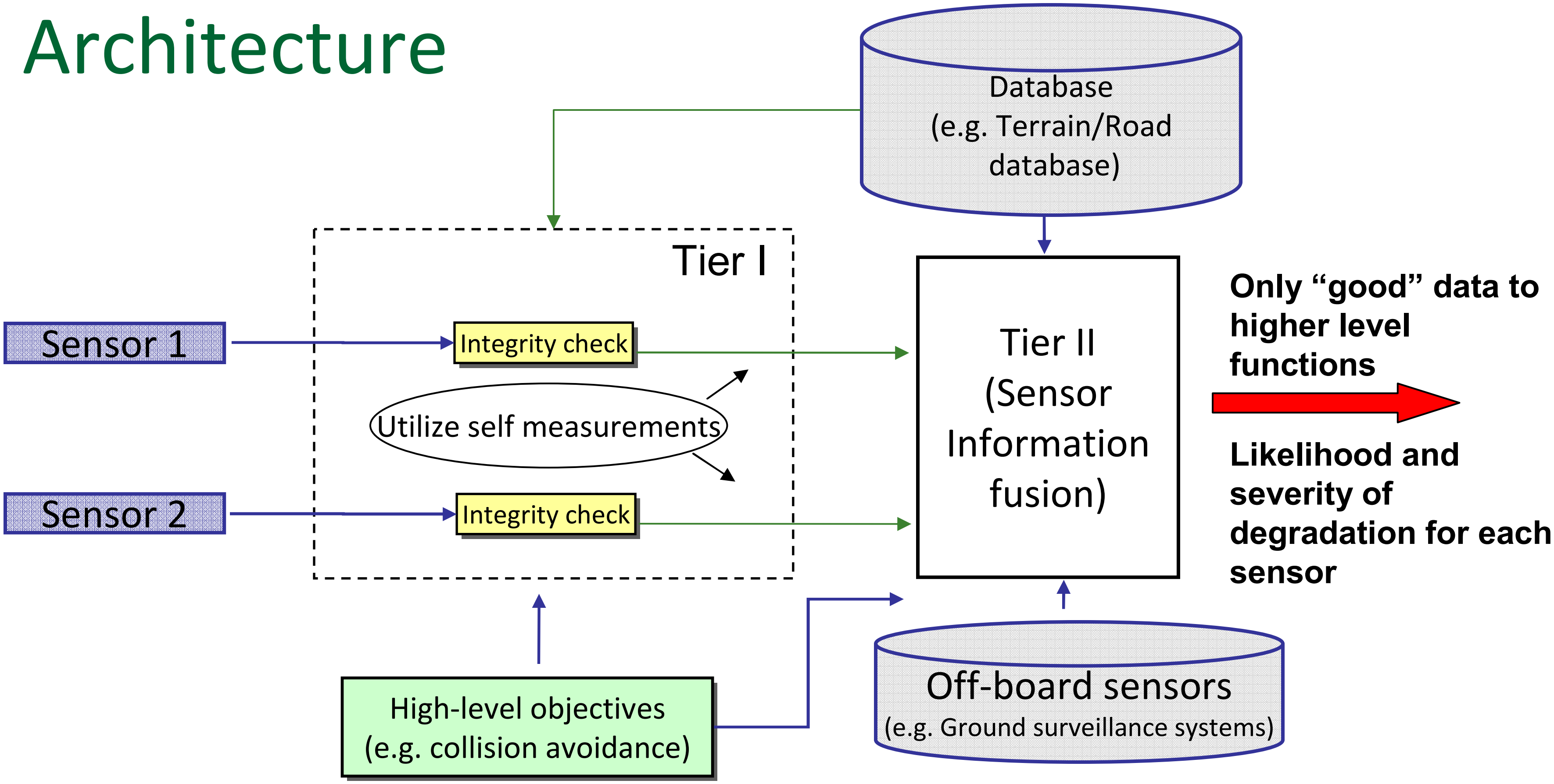
- Integrity classification based on severity and probability of occurrence

Severity / Sensor	Major	Minor	None
Radar	0.001	.004	.995

Probability of each state

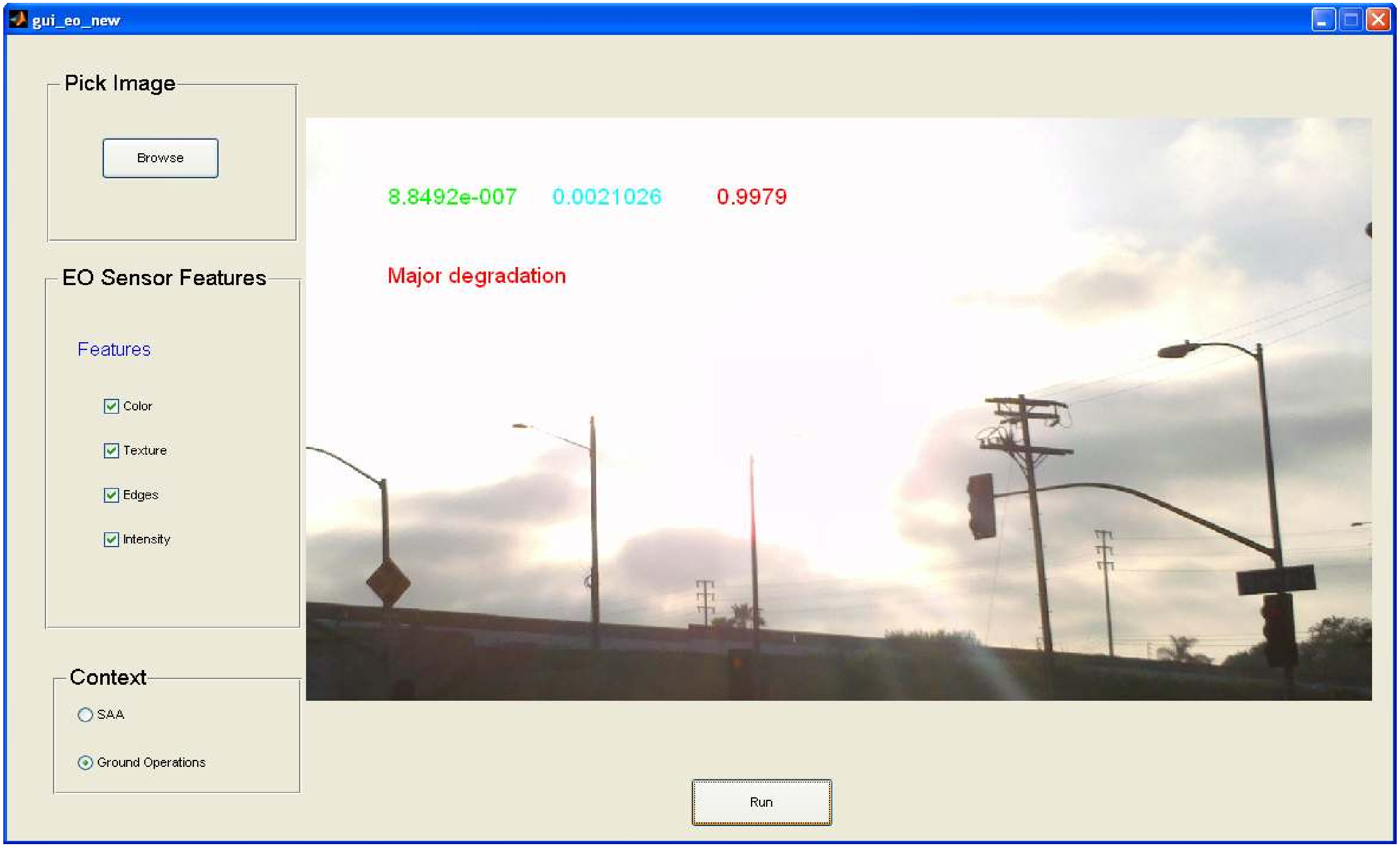
- Compensate for lack of hardware redundancy
- Detect and identify the sources of degradation
- Distinguish between integrity loss due to environment versus the sensor failure
- Accommodate new sensors

Architecture



- Both model based and data based methods for integrity check
  - Examples: Trend analysis, Reasonableness checks, Extended Kalman Filters, Neural Networks, Bayesian Belief Networks
- External information sources, context awareness, knowledge of impact on the performance compensate for lack of h/w redundancy

Example: Camera image quality assessment



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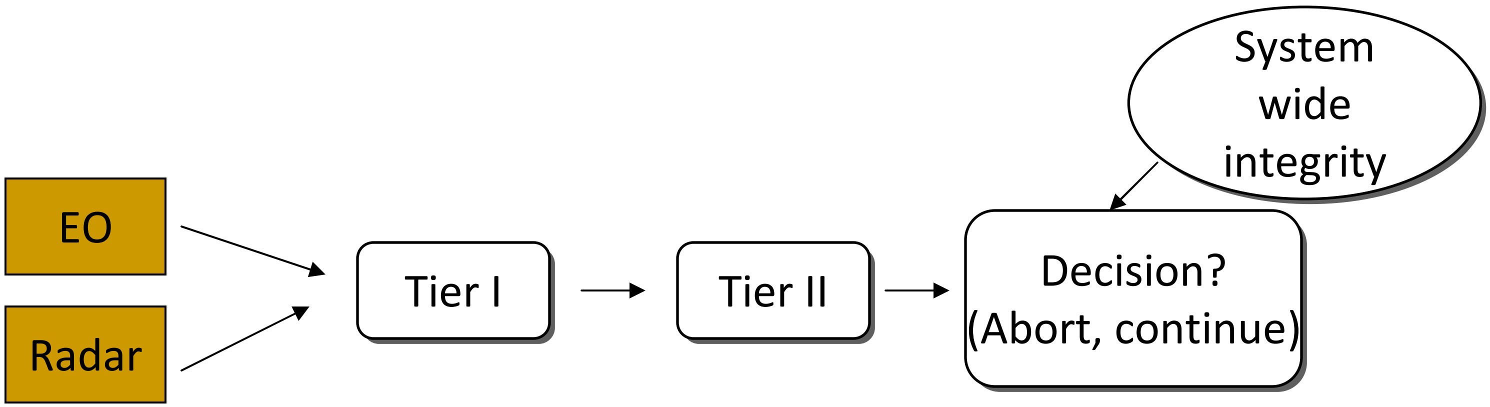
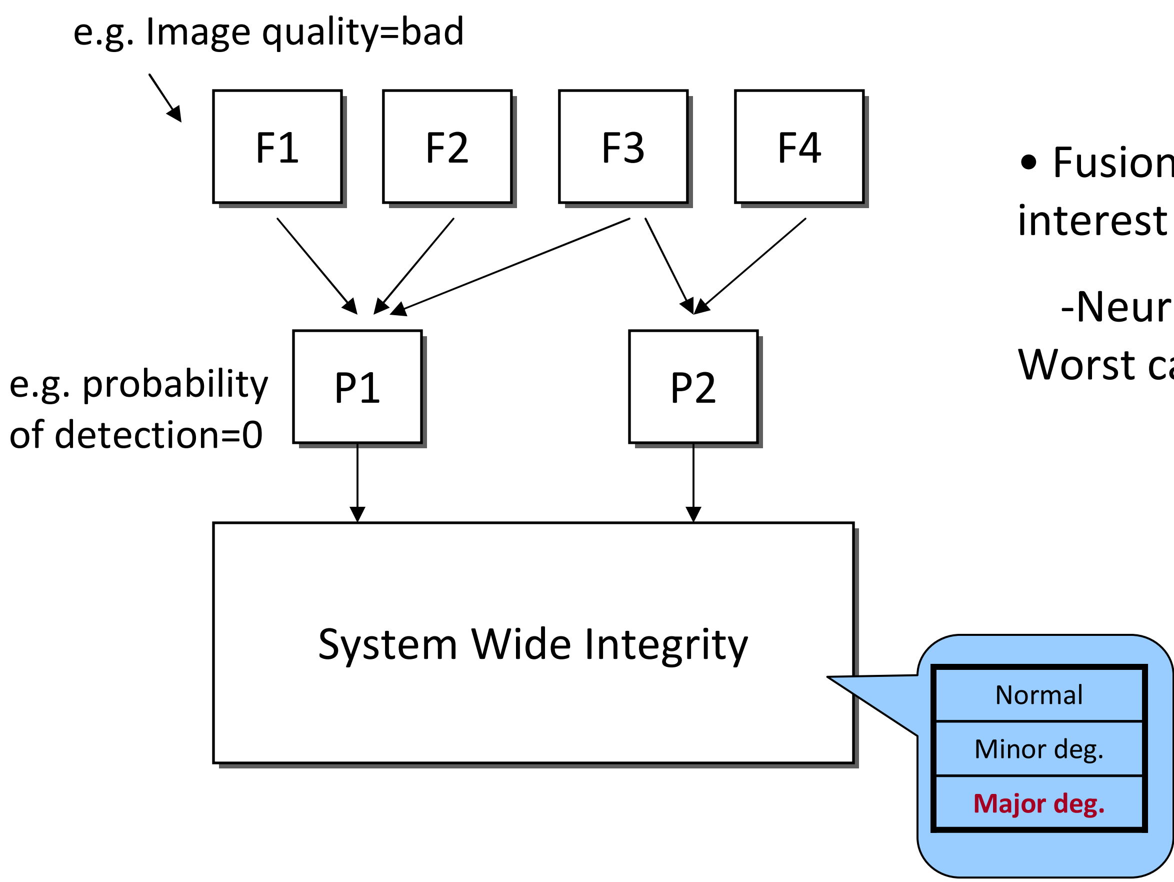
System wide integrity management

Implications of degraded data on the mission performance



- Combine individual faults and their likelihoods into overall system wide Integrity
- Identify parameters which characterize system-wide health
  - SAA and UAS ground operations can be characterized by probability of detection, probability of false alarm, range accuracy, bearing accuracy, time to CPA accuracy
- Identify which parameters are affected by a given fault
  - For example, degradation of EO/IR data due to poor visibility can affect probability of detection as well as probability of false alarm
- Quantify the severity of the effect of degraded parameters on the system performance

System-wide integrity check



- Fusion of faults and parameters of interest

  -Neural networks, Bayesian networks, Worst case analysis

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Conclusions and future work

Integrity management can:

- Reduce risk of failure of system due to degraded data
- Point to source of degradation
- Quantify the degree of degradation and its effects on the system
- Aid in decision making

Future work:

- Use in Sense and Avoid
- Extension to other applications (terminal area operations, autonomous collision avoidance,…)
- Extension to other domains (maritime, automobiles,…)

Questions