Towards an Advanced Self-Monitoring Tracking Module: Leveraging Statistical Hypothesis Tests and Subjective

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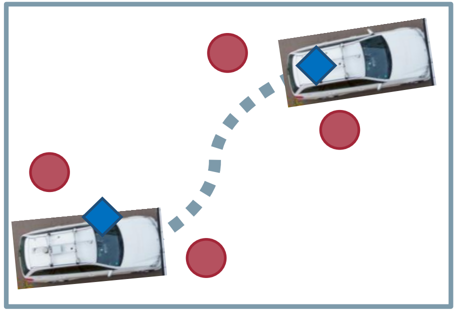

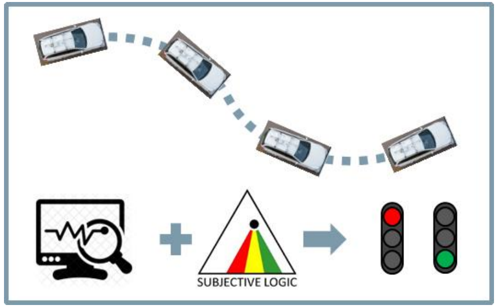

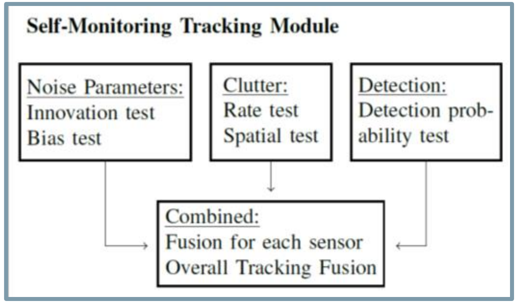

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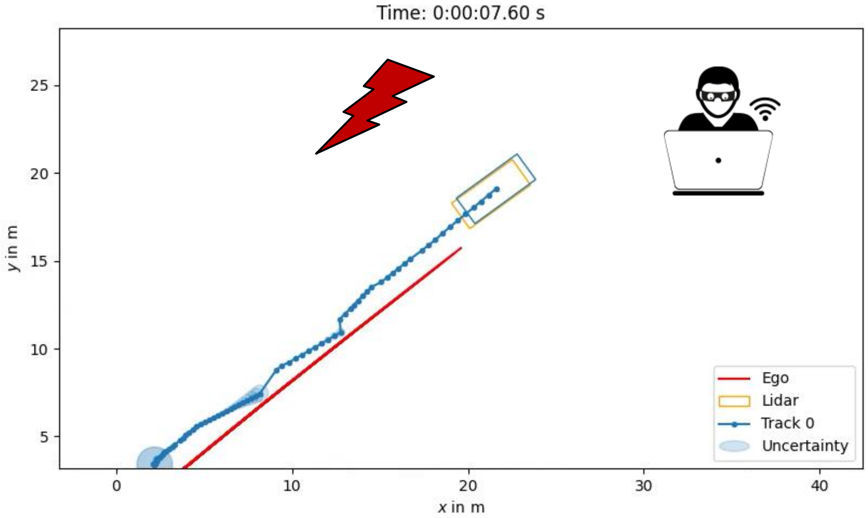
Motivation

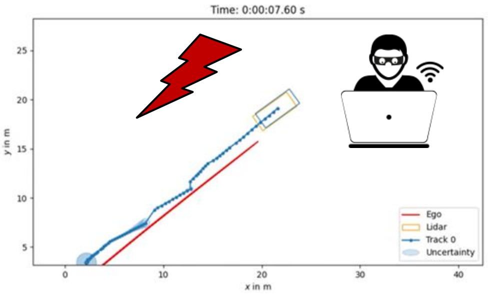
Tracking:



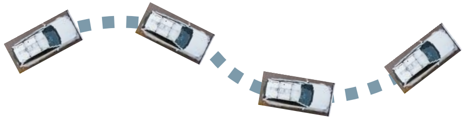
Camera image:

Motivation – Objective

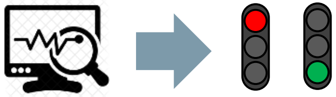
Tracking:



- External disturbances and manipulations of the sensors
  → Affecting the tracking performance



- Self-monitoring and assessment in tracking should detect such disturbances
  - Issue appropriate warnings
  - Make adaptions

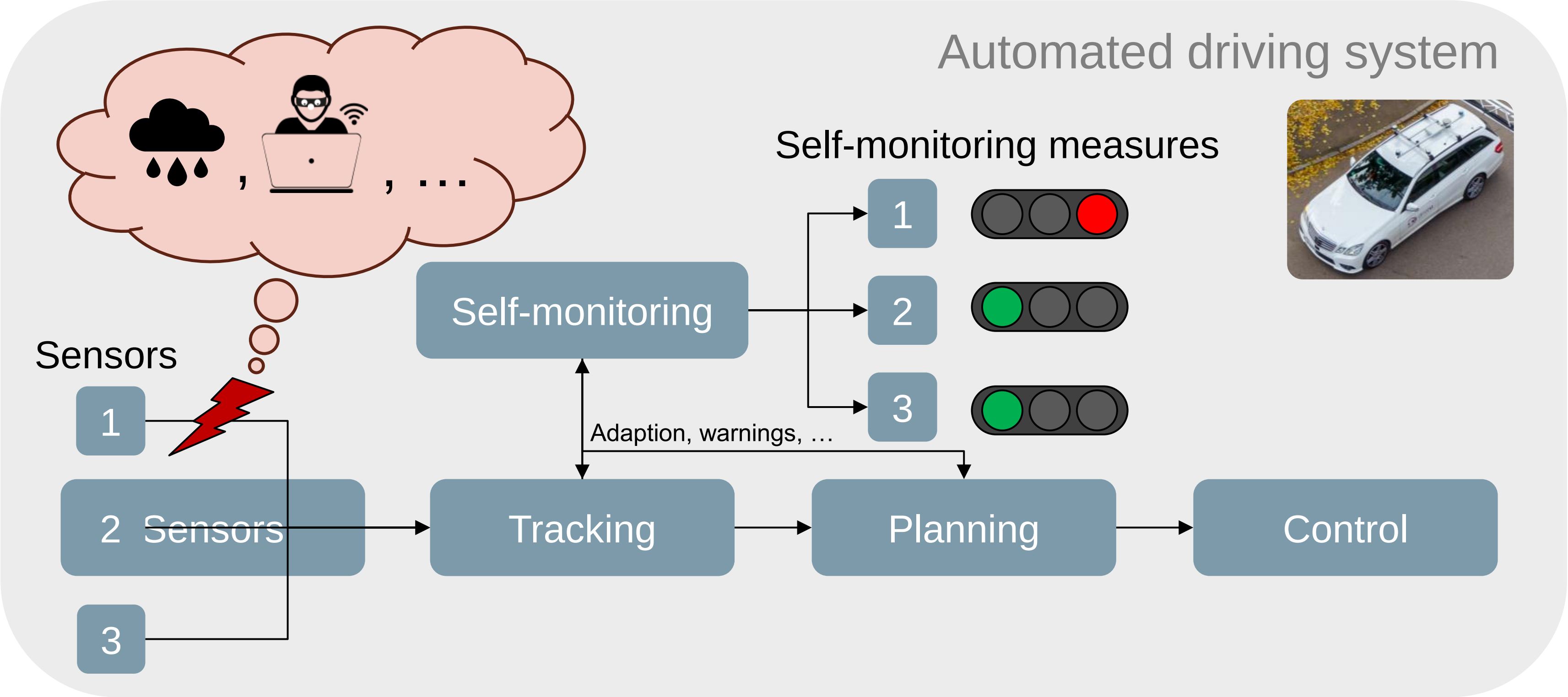


Development of a self-monitoring module in tracking

Tracking

Self-monitoring

Motivation – Self-Monitoring in Tracking Algorithms



Single-Object Tracking (SOT) in Clutter

Challenges in SOT in Clutter:

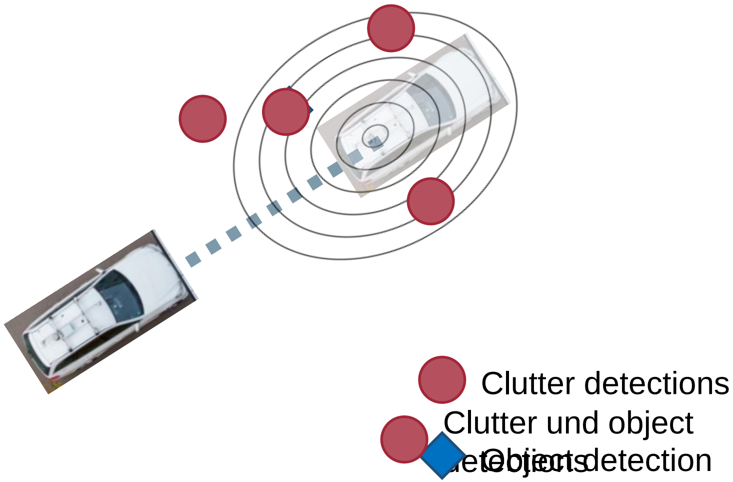
- Time-dependent state estimation
- Noisy measurements

[1]

- Clutter detections
- Missed detection
- Data association

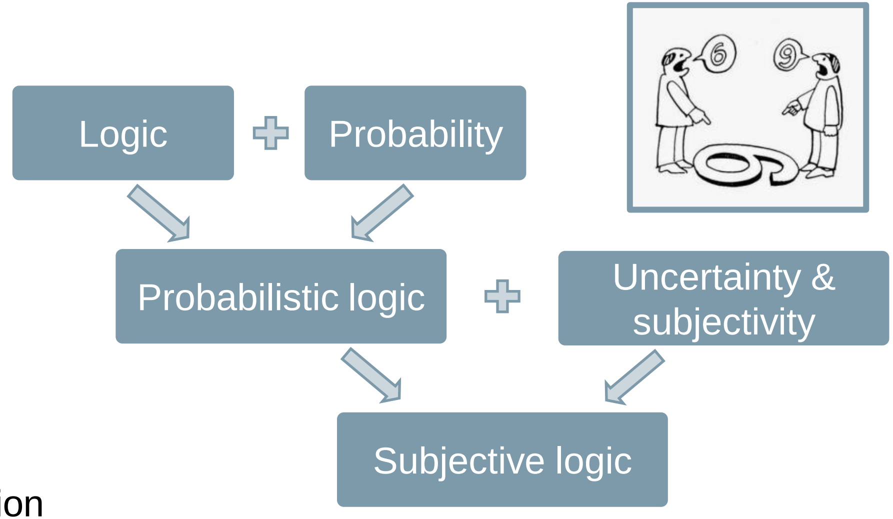
Our Approach:

- Nearest Neighbor association algorithm:
  - Nearest measurement is associated
  - Discard rest (hard decision)
- Tracking: Kalman filter



[1] Griebel, T., Müller, J., Buchholz, M., and Dietmayer, K. "Kalman Filter Meets Subjective Logic: A Self-Assessing Kalman Filter Using Subjective Logic," 2020 IEEE 23rd International Conference on Information Fusion (FUSION), Rustenburg, South Africa, 2020.

Subjective Logic [2] (SL)



- Perception is always subjective
- Modern extension of probabilistic logic for reasoning under uncertainty
- Explicitly includes the uncertainty about probabilities
- Key structure in SL is the opinion representation

$$\omega_X = (\boldsymbol{b}_X, u_X, \boldsymbol{a}_X)$$

  - Belief $\boldsymbol{b}_X$: evidence collected
  - Uncertainty u_X: statistical uncertainty
  - Base rate $\boldsymbol{a}_X$: a priori knowledge

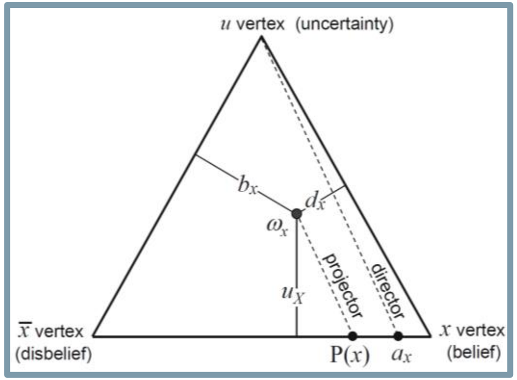


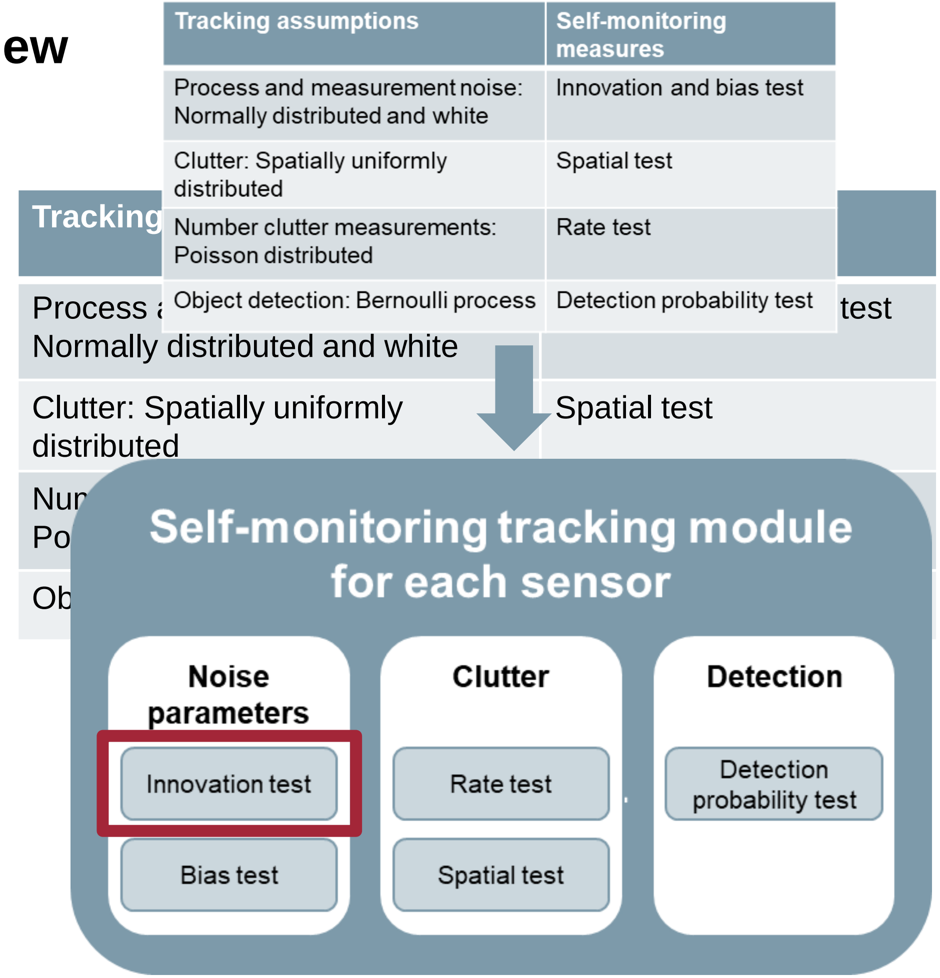
Figure „Sechs oder Neun" from https://leveragepoints.org/2017/10/31/alles-eine-frage-der-perspektive/

[2] Jøsang, A., "Subjective Logic: A Formalism for Reasoning Under Uncertainty," Heidelberg: Springer, 2016.

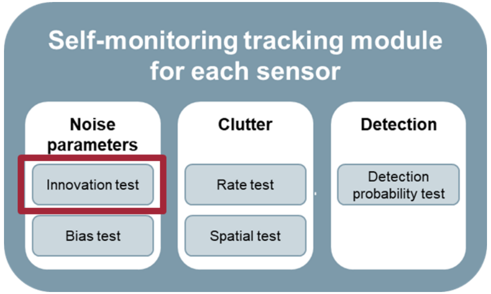
Self-Monitoring Approach – Overview

- Using hypothesis tests to test all statistical assumptions in the tracking algorithm
- Tests can be sorted into different monitoring categories: Noise parameters, clutter, and detection
- Subjective logic opinions can be generated using the hypothesis test results
- Self-monitoring measures can be obtained

→ Self-monitoring module for each sensor



Self-Monitoring Approach – Innovation Test



- Hypothesis test for the innovation

  $$\gamma_{k+1} = z_{k+1} - \hat{z}_{k+1|k}$$

  based on the normalized innovation squared (NIS)

  $$\varepsilon_{\gamma_{k+1}} = \gamma_{k+1}^T S_{k+1}^{-1} \gamma_{k+1}$$

  towards the chi-squared distribution

- Opinion generation for the innovation test

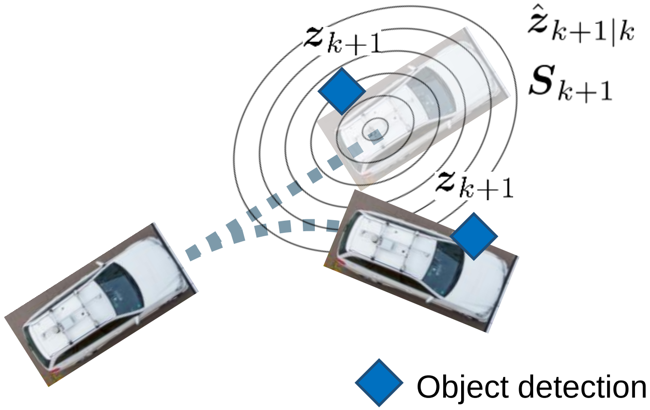
  $$\omega_X = (\boldsymbol{b}_X, u_X, \boldsymbol{a}_X)$$

- Fusion to accumulated sliding window opinion

ω_X	ω_X	ω_X	ω_X	
	ω_X	ω_X	ω_X	ω_X

- Projected probability calculation

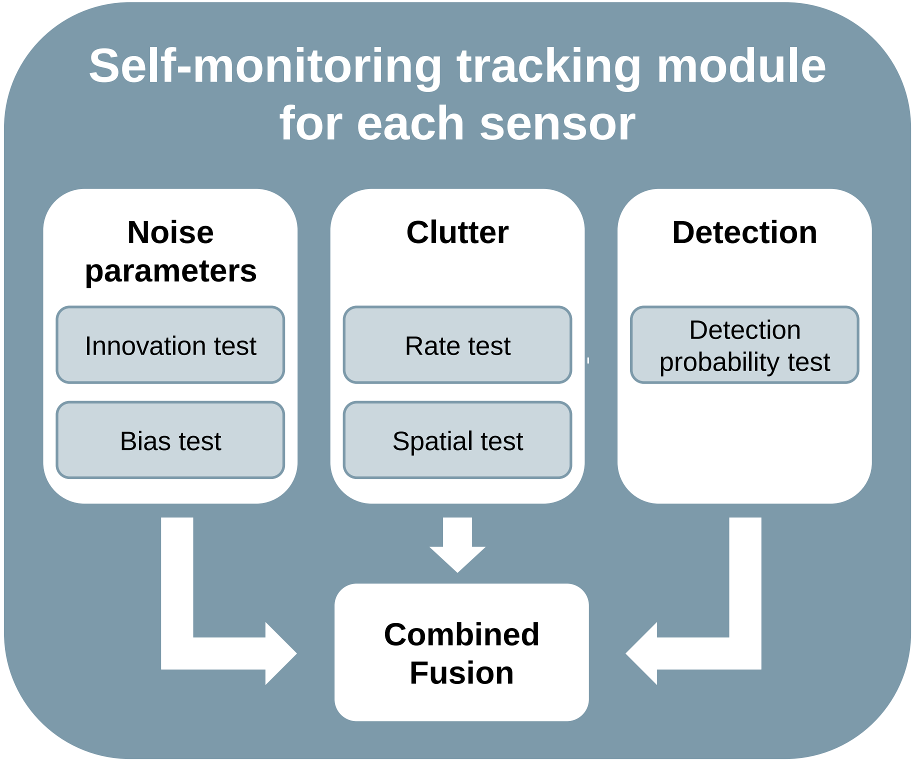
  $$\boldsymbol{P}_X(x) = \boldsymbol{b}_X(x) + \boldsymbol{a}_X(x) u_X$$



Self-Monitoring Approach – Combined Fusion

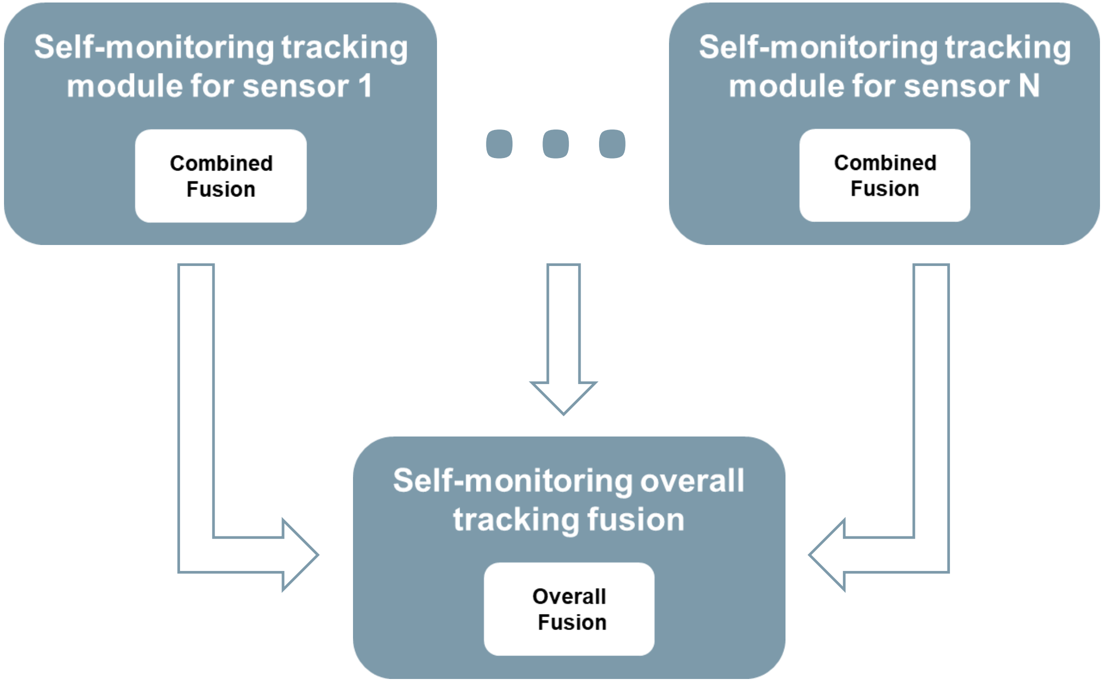
- All hypothesis tests can be performed for each sensor to test all the assumptions' fulfillment
- Using the obtained subjective logic opinions for each test, a combined fusion is obtained in the subjective logic fusion framework

→ Combined self-monitoring score for each sensor



Self-Monitoring Approach – Overall Tracking Monitoring

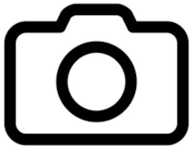
- Self-monitoring module for each sensor obtains combined fusion opinions
- These combined opinions can then be fused to one overall self-monitoring score
- Fusion is performed in the subjective logic reasoning framework



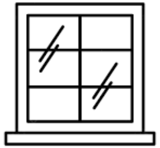
Evaluation – Simulation Scenario in an Urban Environment with Adverse Weather Conditions and Mirroring Effects

Sensor 1 – Lidar

Sensor 2 – Radar



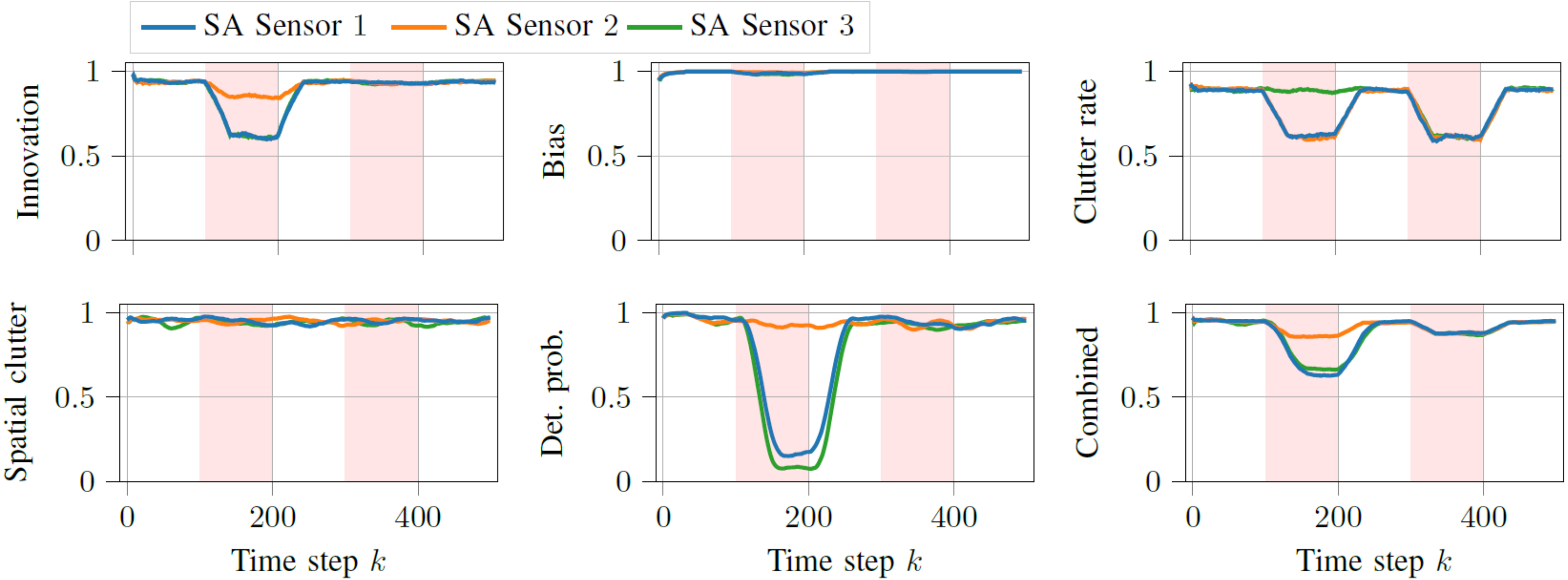
Sensor 3 – Camera



Time steps / **Sensors**	100 – 200 (adverse weather)	300 – 400 (mirroring effects)
Sensor 1 - Lidar	↑ meas. noise & ↓ det. prob. & ↑ clutter rate	↑ clutter rate
Sensor 2 - Radar	↑ clutter rate	↑ clutter rate
Sensor 3 - Camera	↑ meas. noise & ↓ det. prob.	↑ clutter rate

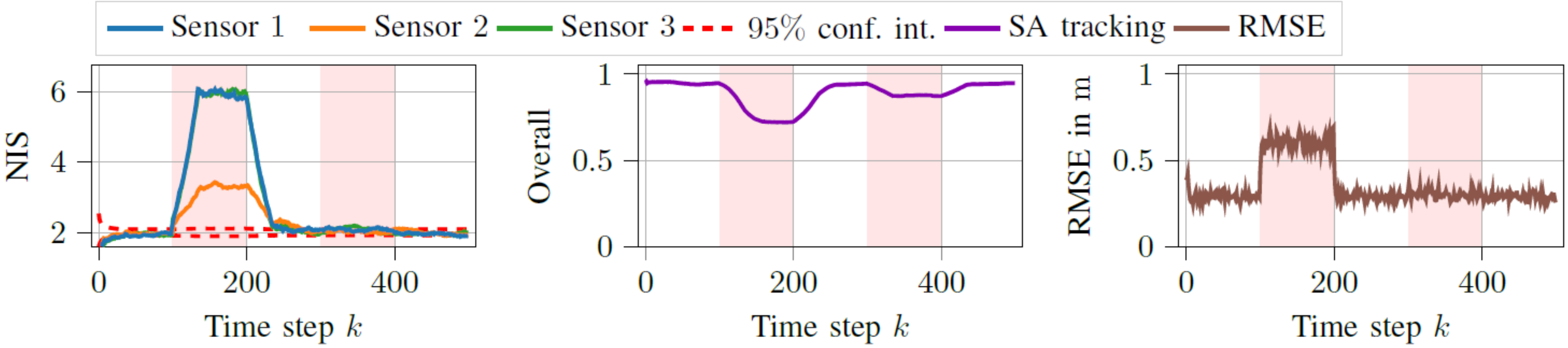
Evaluation – Self-Monitoring Module for Each Sensor

Sensors \ Time steps	100 – 200 (adverse weather)	300 – 400 (mirroring effects)
Sensor 1 - Lidar	↑ meas. noise & ↓ det. prob. & ↑ clutter rate	↑ clutter rate
Sensor 2 - Radar	↑ clutter rate	↑ clutter rate
Sensor 3 - Camera	↑ meas. noise & ↓ det. prob.	↑ clutter rate



Evaluation – Self-Monitoring Overall Tracking and Comparison

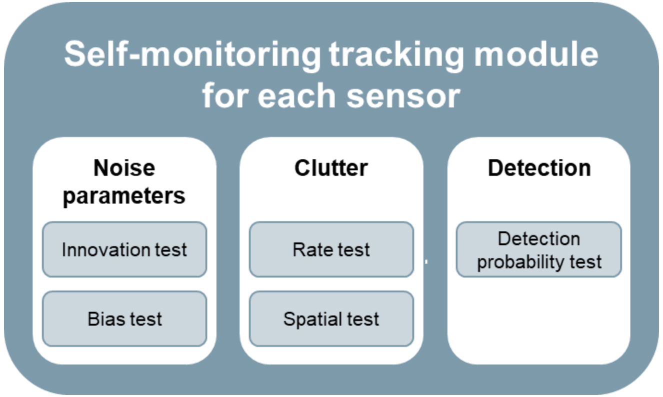
Time steps / Sensors	100 – 200 (adverse weather)	300 – 400 (mirroring effects)
Sensor 1 - Lidar	↑ meas. noise & ↓ det. prob. & ↑ clutter rate	↑ clutter rate
Sensor 2 - Radar	↑ clutter rate	↑ clutter rate
Sensor 3 - Camera	↑ meas. noise & ↓ det. prob.	↑ clutter rate



Conclusion

Our Contribution:

- Self-monitoring tracking module for each sensor using hypothesis testing and subjective logic
- Combined fusion of all monitoring components
- Self-monitoring of the overall tracking system



Future Work:

- Extensions towards multi-object tracking
- Real-world testing and application

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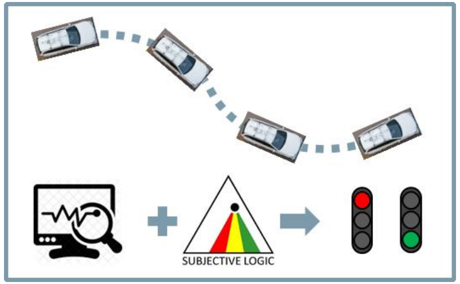

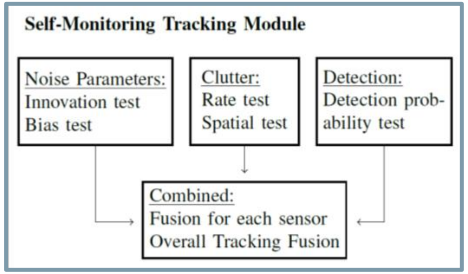

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Thank you for your attention!

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https://www.uni-ulm.de/in/mrm/

References

- [1] Griebel, T., Müller, J., Buchholz, M., and Dietmayer, K. "Kalman Filter Meets Subjective Logic: A Self-Assessing Kalman Filter Using Subjective Logic," 2020 IEEE 23rd International Conference on Information Fusion (FUSION), Rustenburg, South Africa, 2020.
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- [3] Bar-Shalom, Y., Li, X. R., and Kirubarajan, T., "Estimation with Applications to Tracking and Navigation: Theory Algorithms and Software," John Wiley & Sons, 2004.