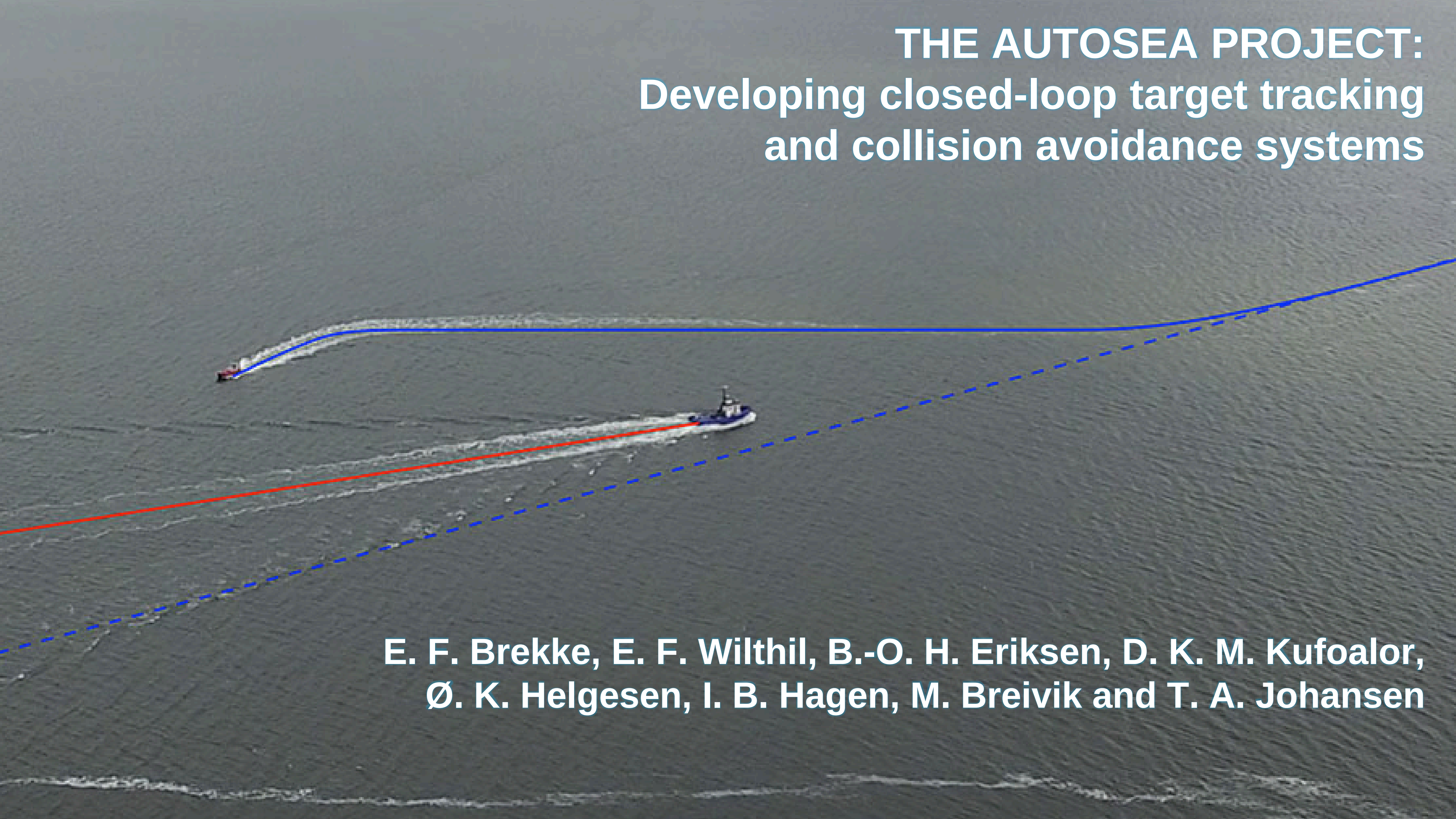
THE AUTOSEA PROJECT: Developing closed-loop target tracking and collision avoidance systems



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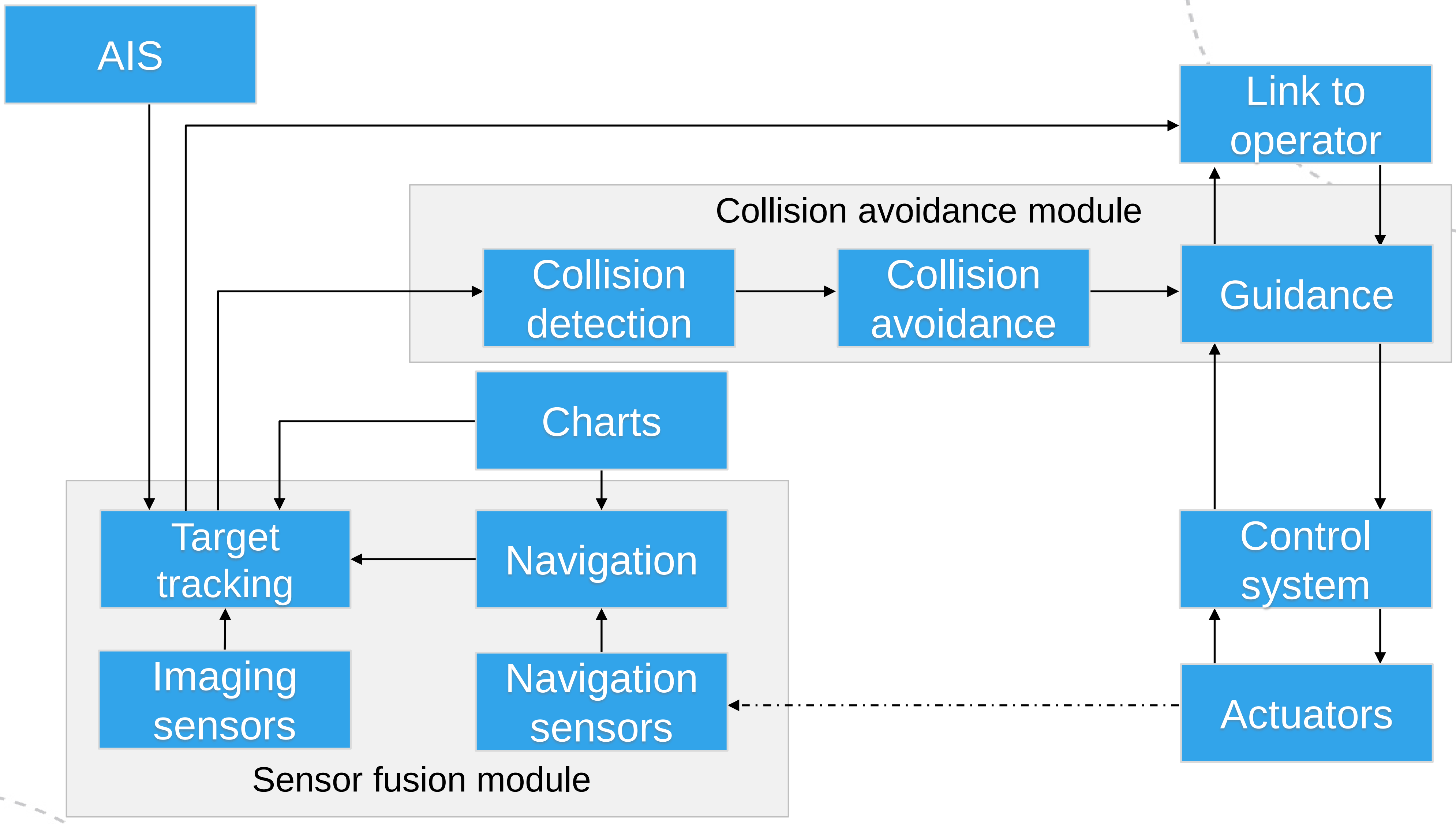
AUTOSEA – facts and figures

- Funded under the MAROFF program of the Research Council of Norway.
- Budget 11MNOK, with contributions from DNV GL, Kongsberg Maritime and Maritime Robotics.
- Duration: August 2015-August 2019.
- The project funded 2 PhD candidates and one postdoctoral fellow.
- In addition, 2 PhD candidates and around 30 MSc candidates are/have been affiliated with the project.

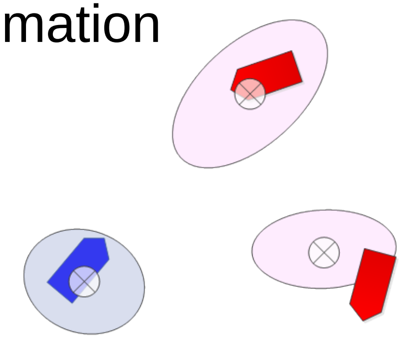
Developed and demonstrated methods for sensor fusion and collision avoidance for autonomous surface vehicles.

Collision avoidance for autonomous ships

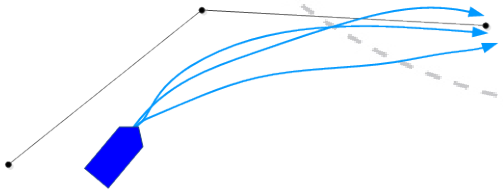


Different types of uncertainties

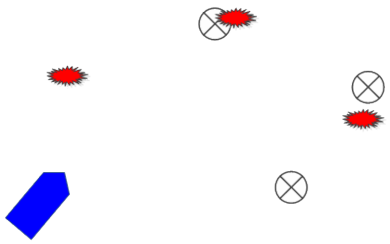
Kinematic estimation uncertainty



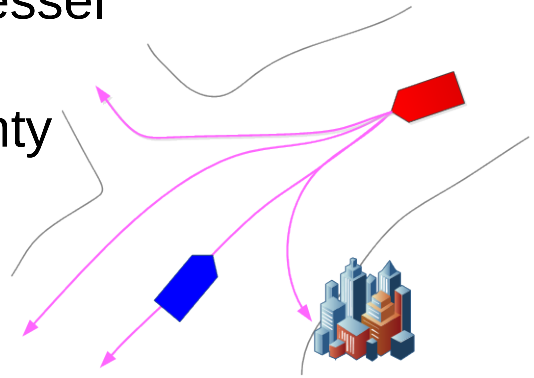
Ownship guidance uncertainty



Data association uncertainty



Target vessel intention uncertainty



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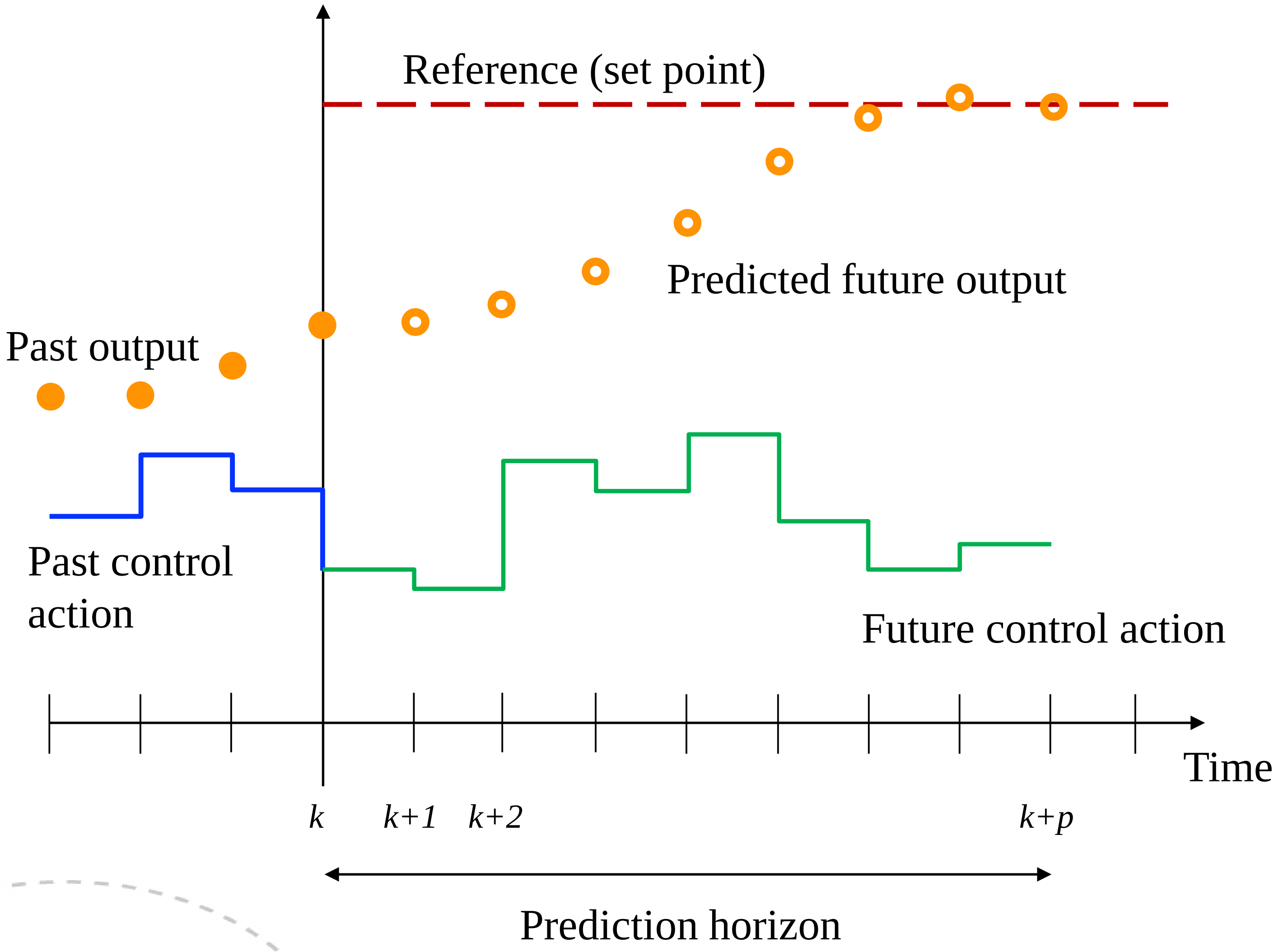
Model predictive control (MPC)



Try several control inputs and choose the one that gives most desirable behavior.

Key design choices include parametrization (of both control input and cost function) and search technique.

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COLAV methods

	Objective function	Constraints	Search strategy	Input parametrization
Velocity Obstacle (VO)	Deviation of velocity + time to collision	Kine. + Risk + CC	Grid search	Des. Course + Speed
Dynamic Window (DW)	Deviation of velocity + Risk	Kine. + Risk	Grid search	Des. Yaw-rate + Speed
Scenario-based MPC (SB-MPC)	Deviation of trajectory + Risk + CC + Trans.	Kine.	Grid search	Des. Course + Speed
Mid-level	Deviation of trajectory + RAM	Kine. + Risk + CC	Gradient search	Course + speed (time-parameterized)
Branching-course MPC (BC-MPC)	Deviation of trajectory + Risk + CC + Trans.	Kine.	Grid search	Segmented trajectory

CC = COLREGS compliance
RAM = Readily Apparent Maneuvers
Kine. = Kinematics limitations
Trans. = Transition costs

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COLAV methods

	Strengths	Weaknesses
VO	Simple and intuitive. COLREGS easily included.	Assumes instantaneous change to desired velocity.
DW	Direct control of yaw-rate gives powerful maneuvers.	Maneuvers not readily apparent.
SB-MPC	Flexible and economic cost function. Thoroughly verified in experiments.	Does not accommodate sequences of plans (in current version).
Mid-level	Can plan far ahead in time (essentially a global method)	Susceptible to local minima.
BC-MPC	Gives readily apparent maneuvers.	Less elegant cost function than SBMPC.

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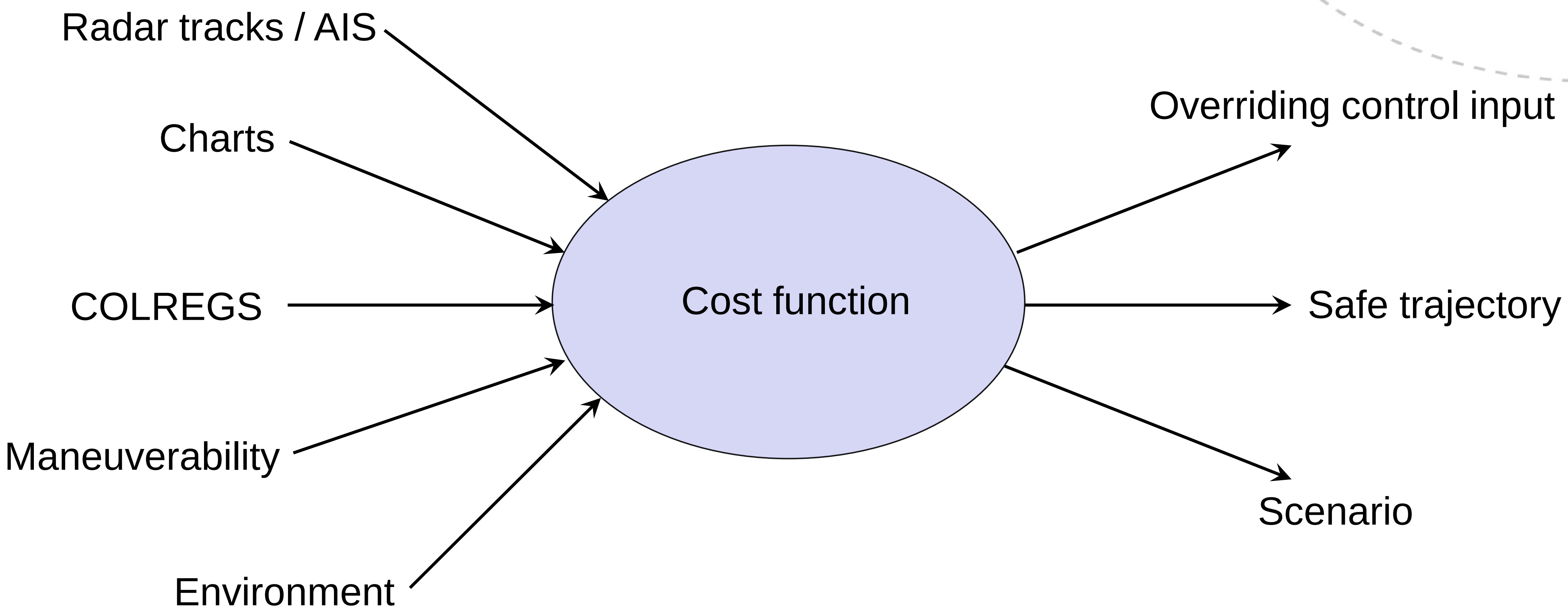
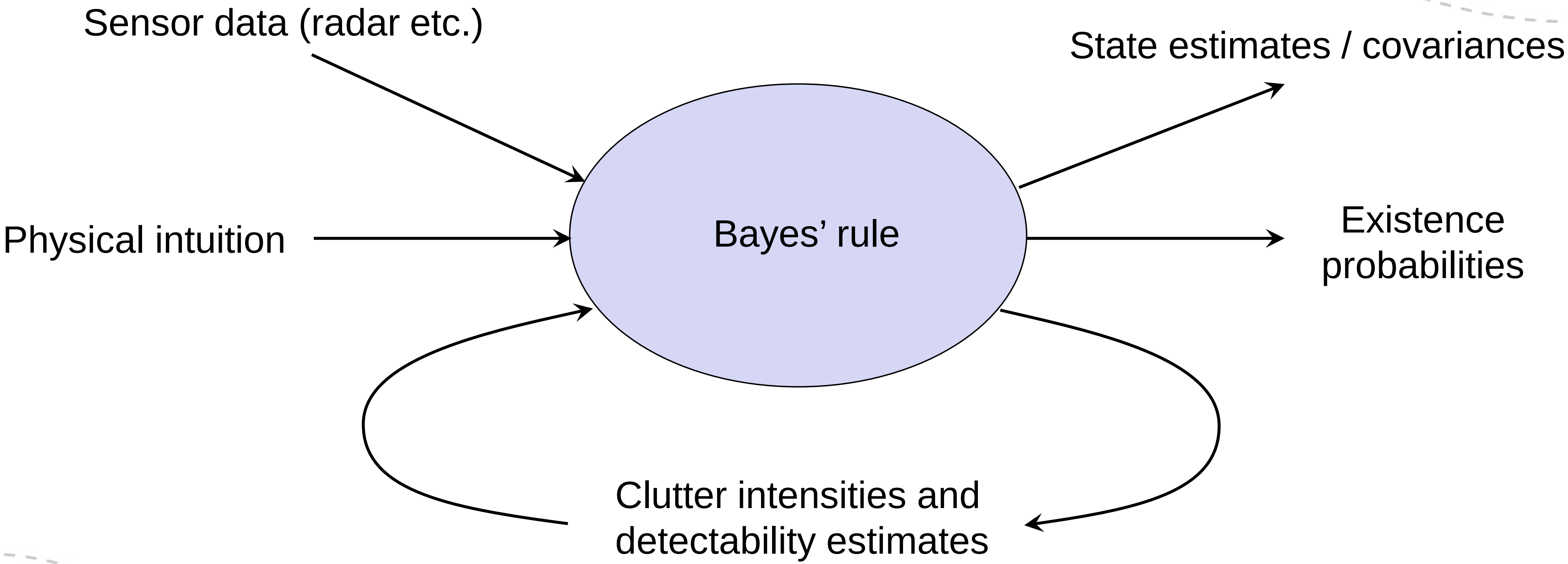
Why MPC: Explainability

Can the system explain its own reasoning?



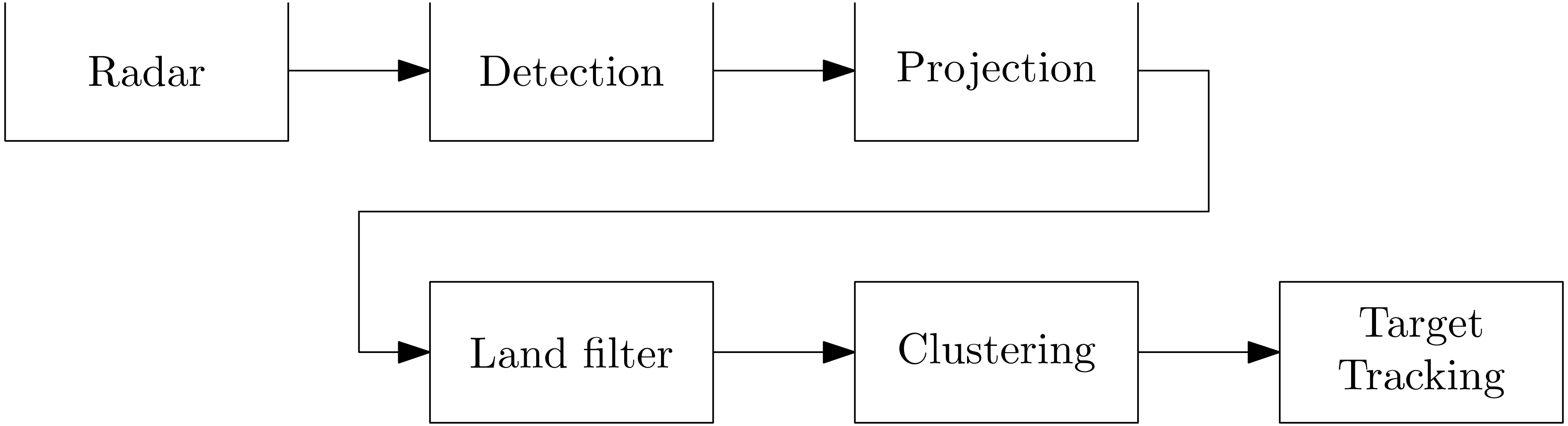
Explainability in sensor fusion ➩ Bayesian inference

All sensor information is qualified by tracking algorithms with Bayesian underpinnings before entering the control system.



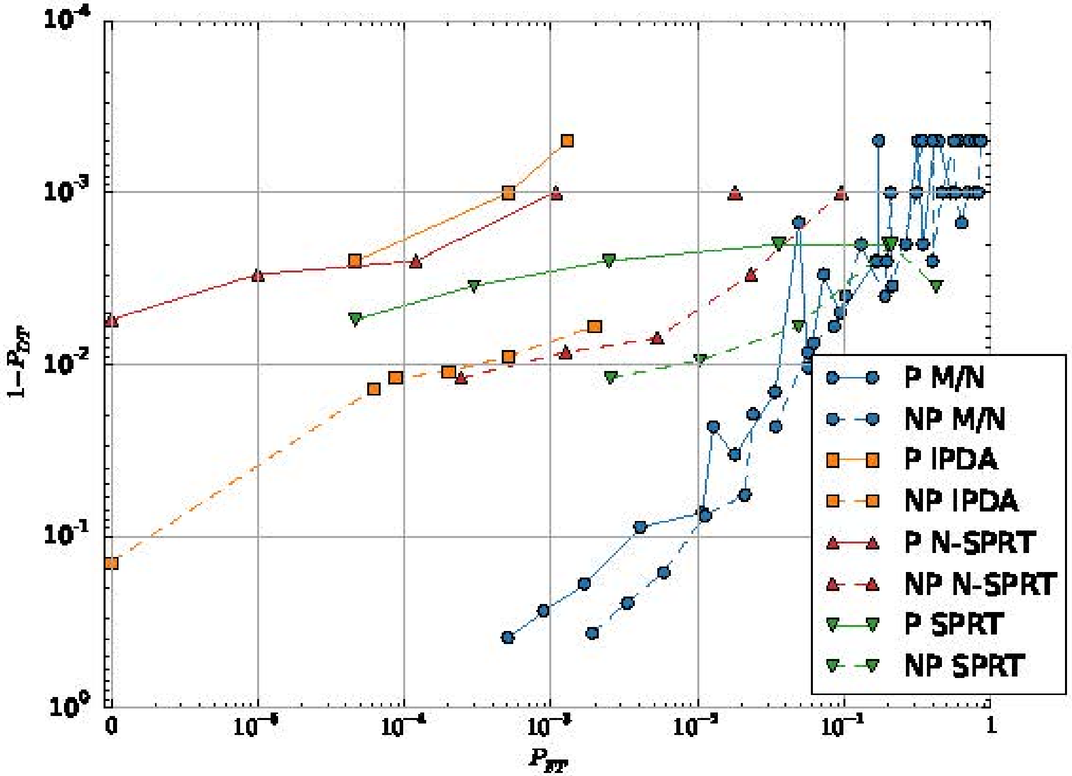
Radar tracking processing pipeline

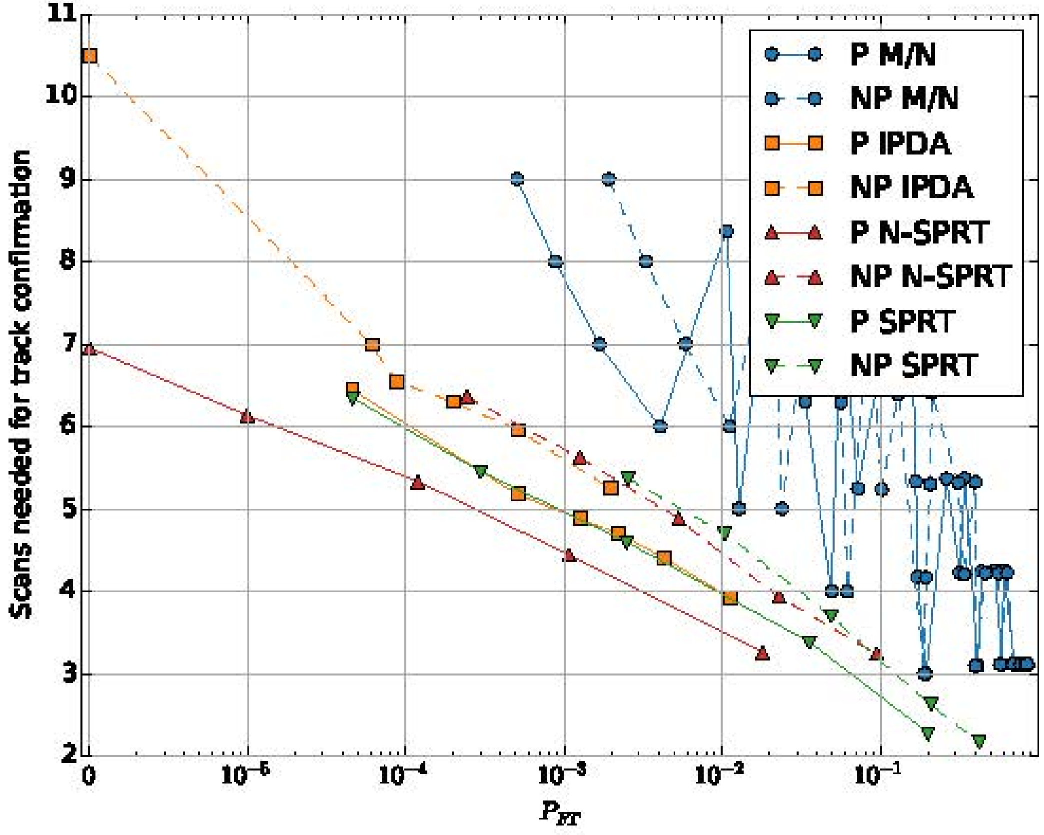
- Several steps transform raw data to point measurements
- In addition to the radar data, this uses nautical charts



Detection performance analysis of radar tracking

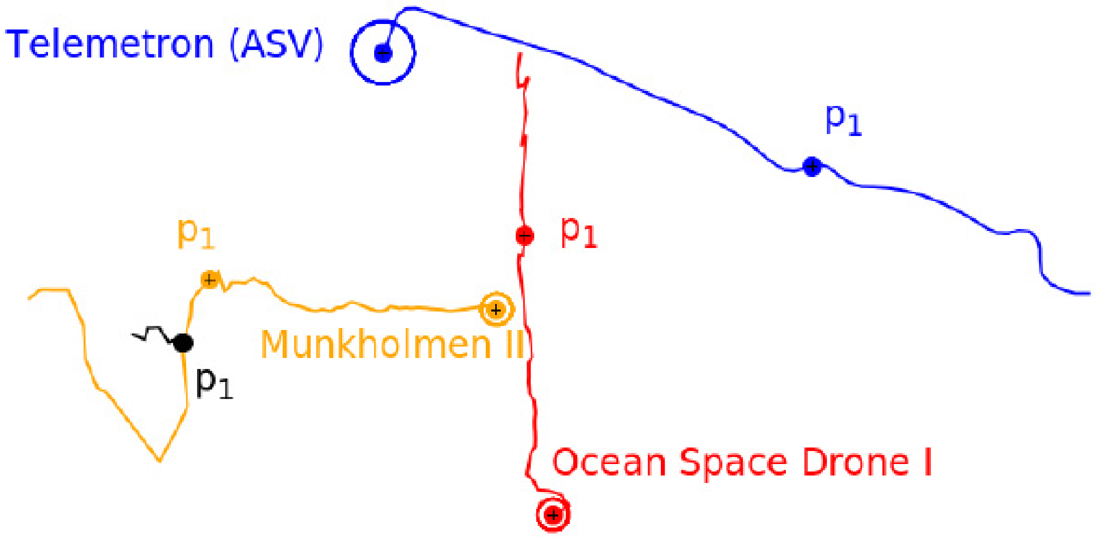
How well are different **track initiation** methods performing?





Obstacle management interface

- Keep both obstacles currently being tracked, and obstacles whose tracks recently were terminated in the system
- Use a decaying track-loss factor to gradually reduce the relevance of the latter kind.



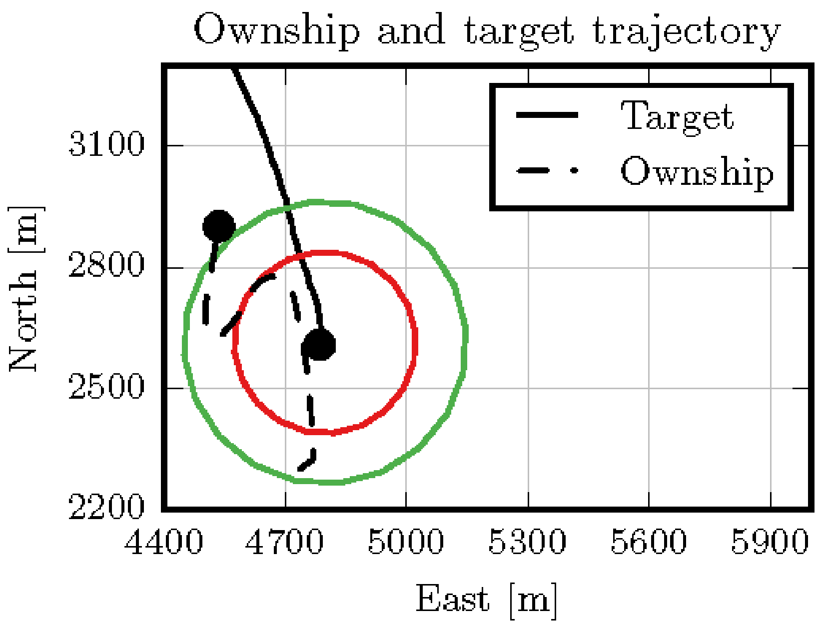
Sudden changes in situational awareness when, e.g., a track is lost and reacquired, can lead a COLAV system to make dangerous actions.

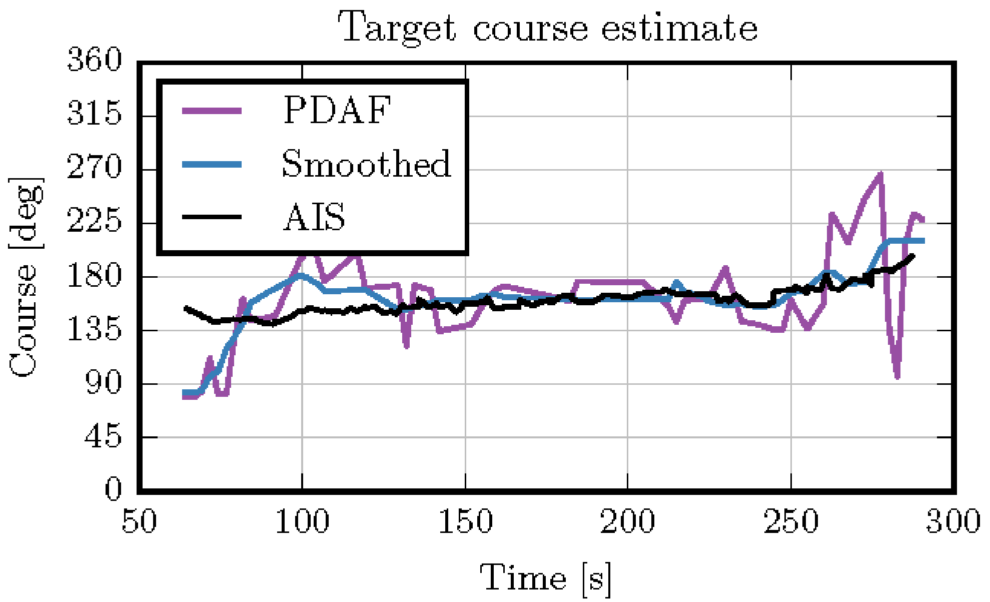
Overview of experiments

When	Where	COLAV method	Data source	Ownship	Target ship
May 2017	Near Munkholmen	DW	Radar	Telemetron	Motorboat of the Autosea students
May 2017	Near Munkholmen	SB-MPC	AIS	Telemetron	Munkholmen 2
Oct. 2017	Near Munkholmen	BC-MPC	Radar	Telemetron	Ocean Space Drone 2
Nov. 2017	Den Helder, NL	SB-MPC	AIS	Telemetron	RIB of Dutch navy ++
Sept. 2018	Near Munkholmen	SB-MPC BC-MPC DRVO	Radar	Telemetron	Ocean Space Drone 2 Munkholmen 2
June 2019	Near Munkholmen	SB-MPC BC-MPC	AIS Radar	Telemetron	Munkholmen 2 FF Gunnerus

COLAV experiments May 2017: DW with Radar

- Telemetron (ownship) vs 17-foot motorboat
- COLAV based on radar tracking (PDAF) and Dynamic Window (DW).





⇨ **Need a COLAV method that is less sensitive to velocity estimate fluctuations.**

⇨ **COLREGS compliance mandatory?**

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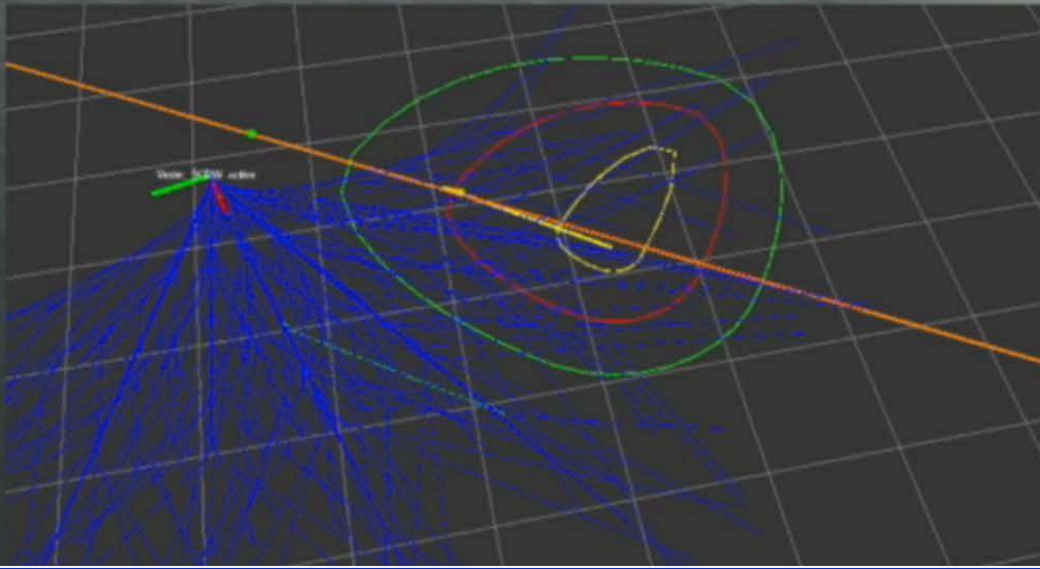
The Branching Course MPC method with radar tracking Trondheimsfjorden, October 2017

Our first successful experiments with radar tracking.

- Sharp turn shows proaction in accordance with COLREGS Rule 8B.
- User interface demonstrates the transparency of the MPC approach.
- Collision avoidance method designed to handle fluctuating course estimates.



Scenario-Based MPC with AIS
Den Helder, NL, November 2017

- Transition costs prevent wobbling.
- Behaviors close to the expectations of an experienced mariner.
- Can violate COLREGS if necessary.

Global, local reactive and proactive COLAV methods

- **Global methods:** Methods that come up with a path or trajectory for an entire mission.
- **Local methods:** Methods that come up with a temporary deviation from a desired path, and which aim to return to the path as soon as it is considered safe.
- **Proactive methods:** The ability to make and follow a plan according to situational awareness in a predictable manner.
- **Reactive methods:** Methods whose evasive control inputs depend directly on the state vector through a functional relationship, and other non-proactive methods.
- **Long-term methods:** Methods that aim to utilize a complete information picture.
- **Short-term methods:** Methods that utilize understanding of the vehicle dynamics to provide more sudden evasive maneuvers.

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Current and future research building on Autosea

Multi-sensor fusion and fundamentals of tracking

- Fusion of EO cameras, IR cameras, radar and lidar
- Georeferencing for passive sensors
- Detectability models for radar tracking
- Random finite set (RFS) foundations for multi-target tracking methods

Approaching the shore and harbors

- Include shore constraints in COLAV methods
- Simultaneous localization and mapping (SLAM) vs. non-SLAM localization
- Extended object tracking

Is this big object a ship or the shore-side?

Situational awareness for autonomous ships

- Long-term vessel trajectory prediction
- Fusion of AIS and exteroceptive sensors
- Pose estimation
- Risk-based COLAV

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Final remarks

- We have demonstrated autonomous maritime collision avoidance based on AIS and radar tracking in a variety of scenarios.
- We are moving towards scenarios where margins of safety are smaller and richer sensor information is needed.

Situational awareness for autonomous ships is perhaps more characterized by large numbers of possibilities, both for what can possibly happen and for what the ship can do, than similar systems for cars, airplanes or underwater vehicles.

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Selected publications

- Kufoalor et al.: “Autonomous Maritime Collision Avoidance: Field Verification of Autonomous Surface Vehicle Behavior in Challenging Scenarios”. Journal of Field Robotics, November 2019.
- Eriksen et al.: “The Branching-Course MPC Algorithm for Maritime Collision Avoidance”. Journal of Field Robotics, August 2019.
- Helgesen et al.: “Sensor Combinations in Heterogeneous Multi-sensor Fusion for Maritime Target Tracking”, in Proc. FUSION, Ottawa, Canada, 2019.
- Kufoalor et al.: “Autonomous COLREGs-Compliant Decision Making using Maritime Radar Tracking and Model Predictive Control”, in Proc. ECC, Naples, Italy, June 2019.
- Wilthil et al.: “Estimation of Target Detectability for Maritime Target Tracking in the PDA Framework”, in Proc. FUSION, Ottawa, Canada, 2019.
- Eriksen et al.: “Radar-based Maritime Collision Avoidance using Dynamic Window”, in Proc. IEEE Aerospace Conference, MT, USA, March 2018.
- Hagen et al.: “MPC-based Collision Avoidance Strategy for Existing Marine Vessel Guidance Systems”, in Proc. ICRA, Gold Coast, Australia, May 2018.
- Wilthil et al.: “A target tracking system for ASV collision avoidance based on the PDAF”, in “Sensing and Control for Autonomous Vehicles”, Springer, 2017.

Thank you for your attention!

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