Galileo\EGNOS – Perspektiven und Anwendungen im maritimen Umfeld

Zuverlässige Navigation ist die Basis für hochautomatisierte Schiffe – Projekt GALILEOnautic

8. September 2021

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Universität Rostock
Traditio et Innovatio

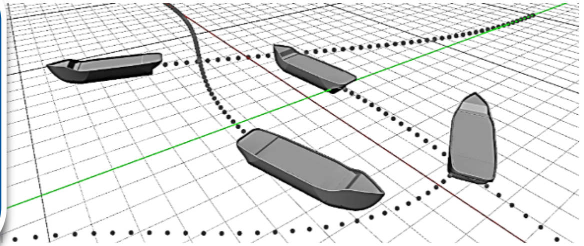
Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

Why Automatization?
Some examples

Increased safety



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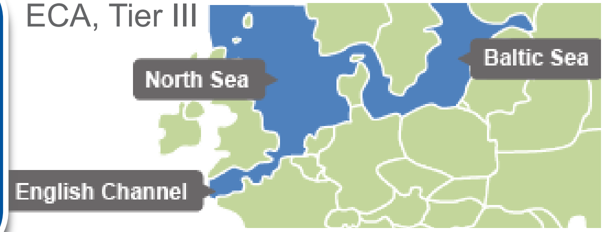
Considering environment protection

ECA, Tier III



(IMO.de,2015)

Cost pressure from freight transport by road

(balogshipping.ch)

Maneuvring at physical limits

©Voith Turbo

Personnel shortage & reduction of operational costs

(Rechnungswesen-verstehen.de)

Political & financial support at state, federal and EU level

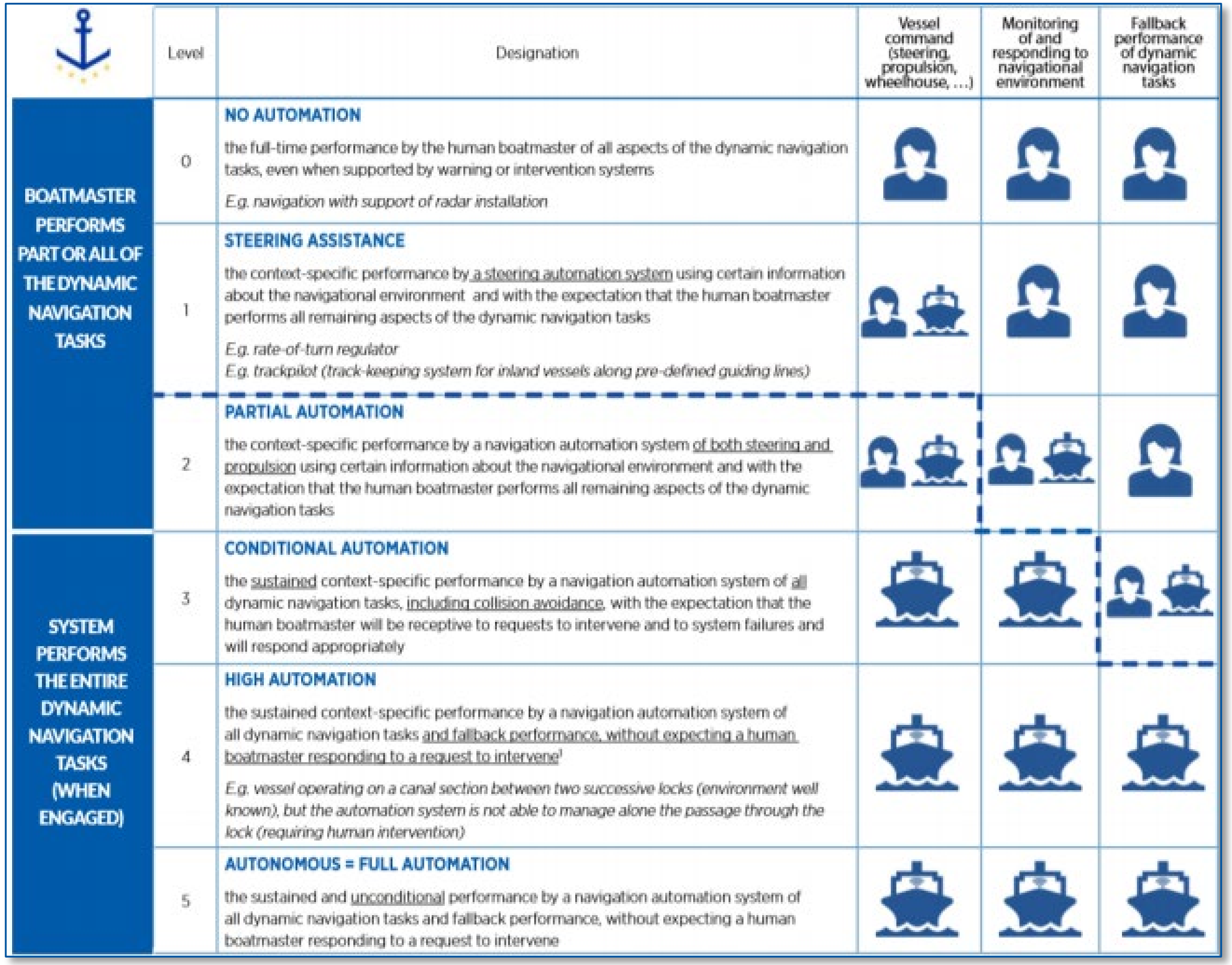
(akademie-sport-gesundheit.de)

Permanent data availability enables: Digitization

- Intelligent data analysis
- Maintenance planning
- Fleat manage-ment
- Traffic flow management
- Other business cases

Research & development steps

towards autonomous (=full automated) inland shipping



	Level	Designation	Vessel command (steering, propulsion, wheelhouse, ...)	Monitoring of and responding to navigational environment	Fallback performance of dynamic navigation tasks
BOATMASTER PERFORMS PART OR ALL OF THE DYNAMIC NAVIGATION TASKS	0	**NO AUTOMATION** the full-time performance by the human boatmaster of all aspects of the dynamic navigation tasks, even when supported by warning or intervention systems *E.g. navigation with support of radar installation*			
	1	**STEERING ASSISTANCE** the context-specific performance by a steering automation system using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks *E.g. rate-of-turn regulator* *E.g. trackpilot (track-keeping system for inland vessels along pre-defined guiding lines)*			
	2	**PARTIAL AUTOMATION** the context-specific performance by a navigation automation system of both steering and propulsion using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks			
SYSTEM PERFORMS THE ENTIRE DYNAMIC NAVIGATION TASKS (WHEN ENGAGED)	3	**CONDITIONAL AUTOMATION** the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks, including collision avoidance, with the expectation that the human boatmaster will be receptive to requests to intervene and to system failures and will respond appropriately			
	4	**HIGH AUTOMATION** the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks and fallback performance, without expecting a human boatmaster responding to a request to intervene[1] *E.g. vessel operating on a canal section between two successive locks (environment well known), but the automation system is not able to manage alone the passage through the lock (requiring human intervention)*			
	5	**AUTONOMOUS = FULL AUTOMATION** the sustained and unconditional performance by a navigation automation system of all dynamic navigation tasks and fallback performance, without expecting a human boatmaster responding to a request to intervene			

Definition for automation in inland navigation
set by CCNR („Zentralkommission für die Rheinschifffahrt “)

- Assistance systems to support operator
- Assisted collision avoidance
- Automated track control systems
- Traffic situation survey and dynamic track adaption
- Cooperative actions with other vessels
- Energy optimal operation
- Operation control considerig traffic rules
- Risk analysis and traffic-situation prediction
- Trajectorie control
- External monitoring and control center
- etc.


Localization & integrity
(ShipInsight.com)

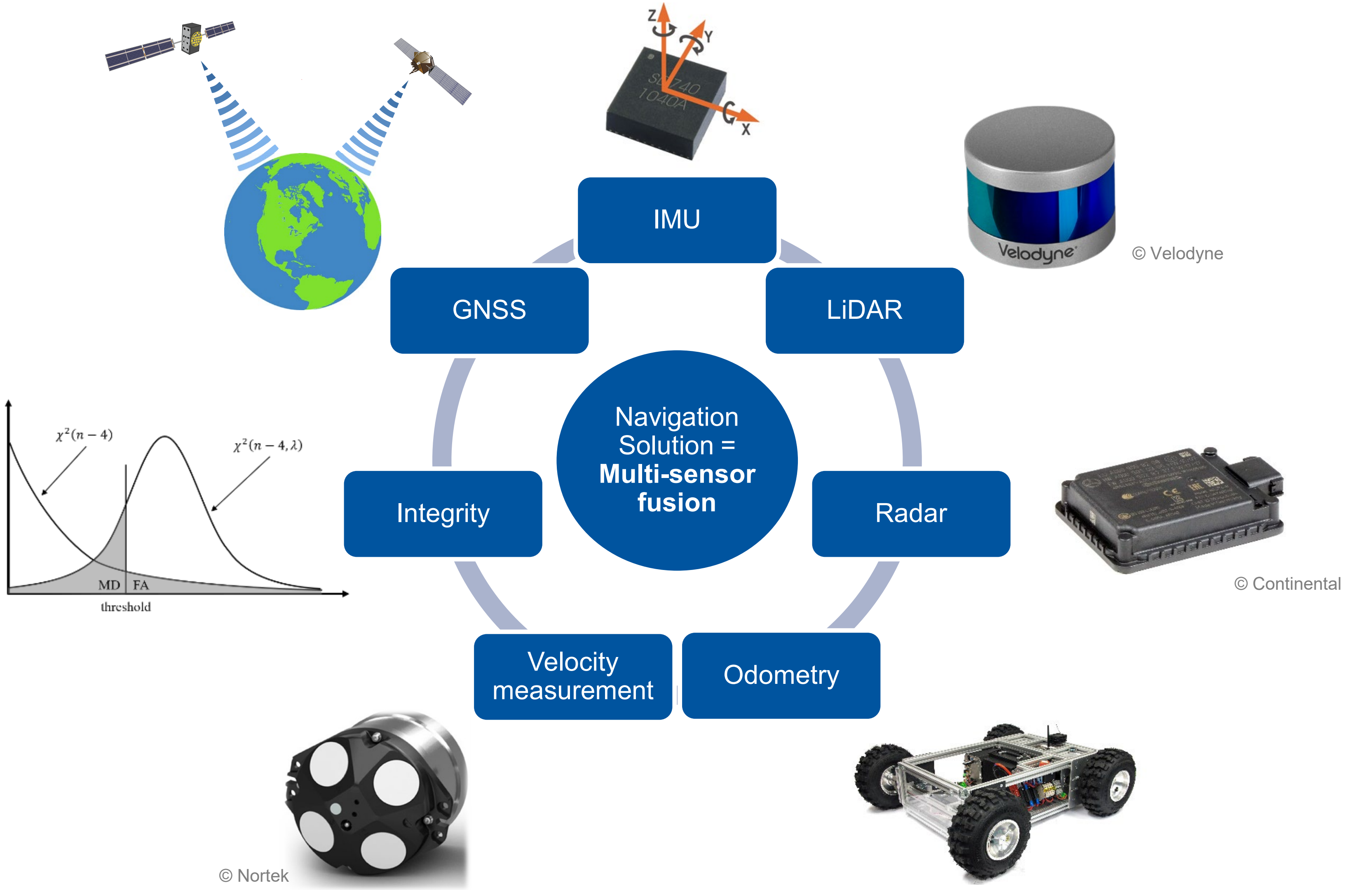
Requirements from the perspective of navigation

Requirements of sensor data for automation

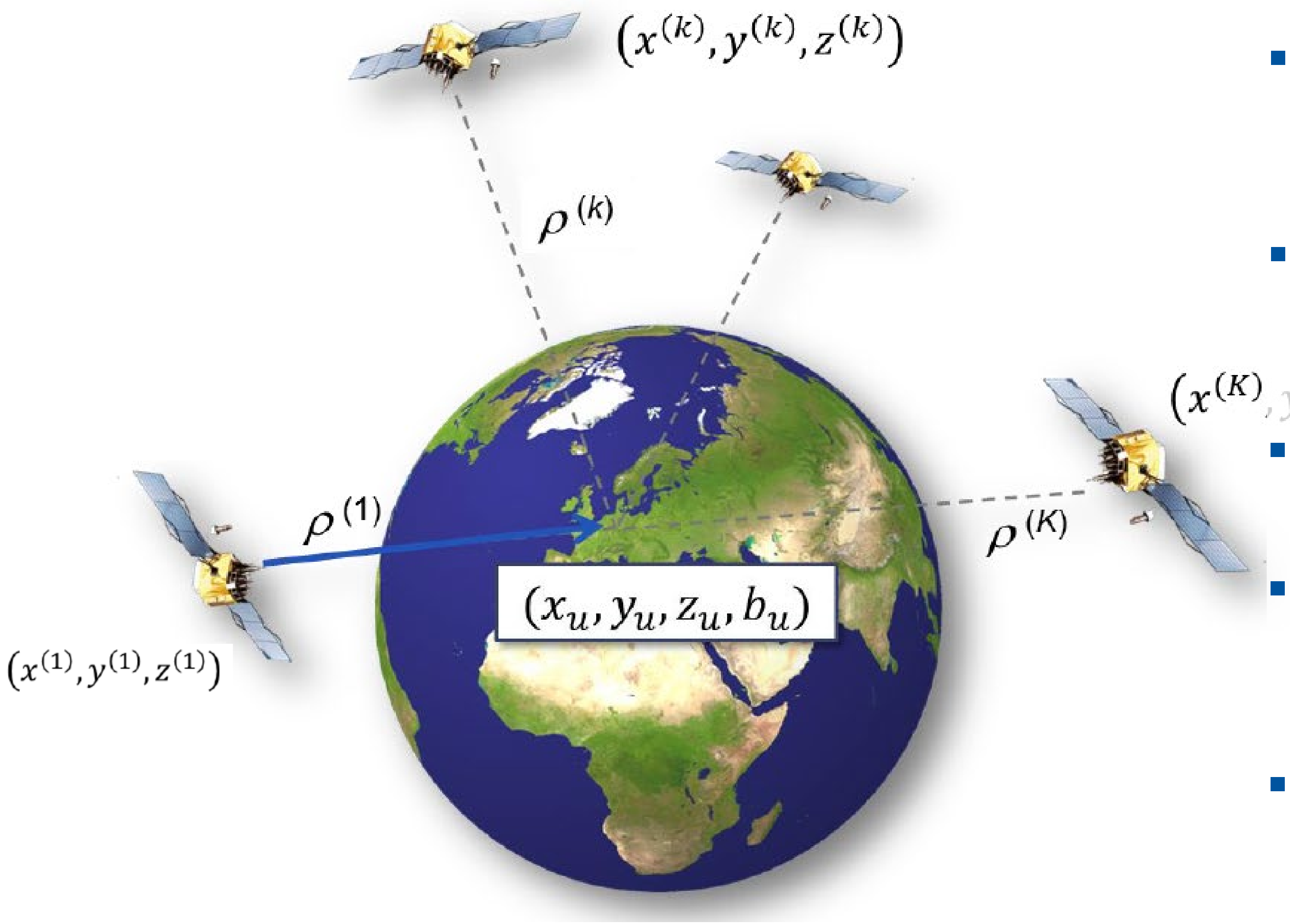
- High accuracy
- High sampling rate
- High availability
- High robustness
- Reliability
- Safety / redundancy
- Smoothness

Safety requirements

- Environmental perception
- Traffic situation detection
- Collision avoidance
- Integrity monitoring



Satellite Navigation
3D Localization & velocity estimation



- Determine time-of-transmission from satellite to receiver/rover
- Distance calculation among rover and satellites using time-of-transmission
- Ego-position estimation via triangulation
- At least 4 satellites needed to determine a 3D position and clock error
- Reception of more than 6 satellites allows to exclude faulty measurements

  (RAIM - Receiver Autonomous Integrity Monitoring)

Features of the Galileo-System

Increased availability

- Civilian system
- Availability guaranteed by law
- Increased coverage due to interoperability with GPS and GLONASS

Increased accuracy

- Dual-frequency mode (E1&E5a) for open service
- Very low noise level
- More accurate correction models
- Use of EGNOS V3 to correct L1/E1 & L5/E5
- PPP-accuracy with Galileo HA service (HAS)

Integrity monitoring and security

- Galileo reports system errors
- Encrypted E6 frequency for military and safty critical applications

➡ **Necessary properties for autonomous applications**

- Satellite launches

  2016/05/24: Satellites 13,14

  2016/11/17: Satellites 16-18

  2017/12/12: Satellites 19-22

  2018/07/25: Satellites 23-26

  Planned end of 2021: Satellites 27-28

  Planned for 2022: Satellites 29-30

Features of the Galileo-System

Increased availability

- Civilian system
- Availability guarant
- I   due to interoperability with GPS a   LONASS

Galileo helps increase confidence in satellite navigation

Increased Accuracy

- Dual-frequency mode (E1&E5a) for open service
- Very low noise level
- More accurat
- Use   to correct L1/E1 & L5/E5
- PPP-accuracy with Galileo HA service (HAS)

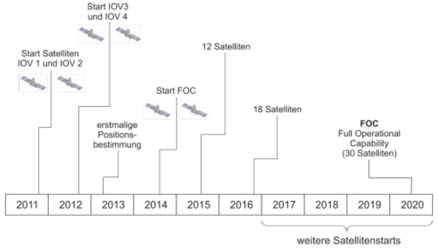
Using Galileo increases position accuracy

Integrity monitoring and security

- Galileo reports system errors
- Encrypted E6 f   and safty critical

Galileo improves detection & identification of signal errors

➡ **Necessary properties for autonomous applications**



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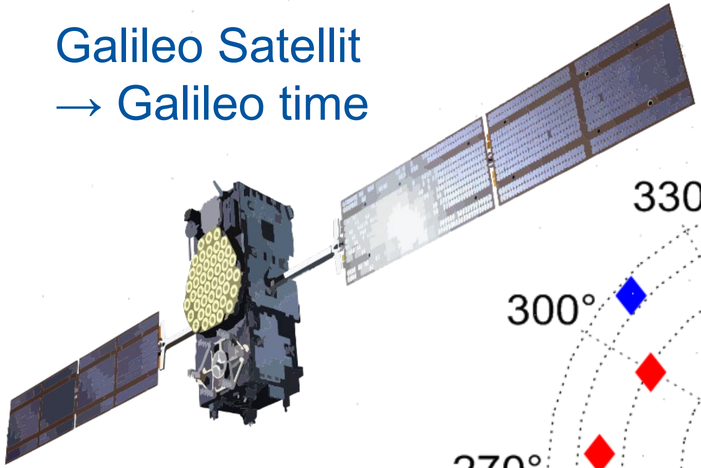
Simultaneous use of GPS & Galileo increases coverage/availability

GPS satellite
→ GPS time

Galileo Satellit
→ Galileo time



Data synchronization

- GGTO message from Galileo offers the possibility to synchronize observations from GPS and Galileo
- This makes time correction of the signal observations for synchronization easy to implement

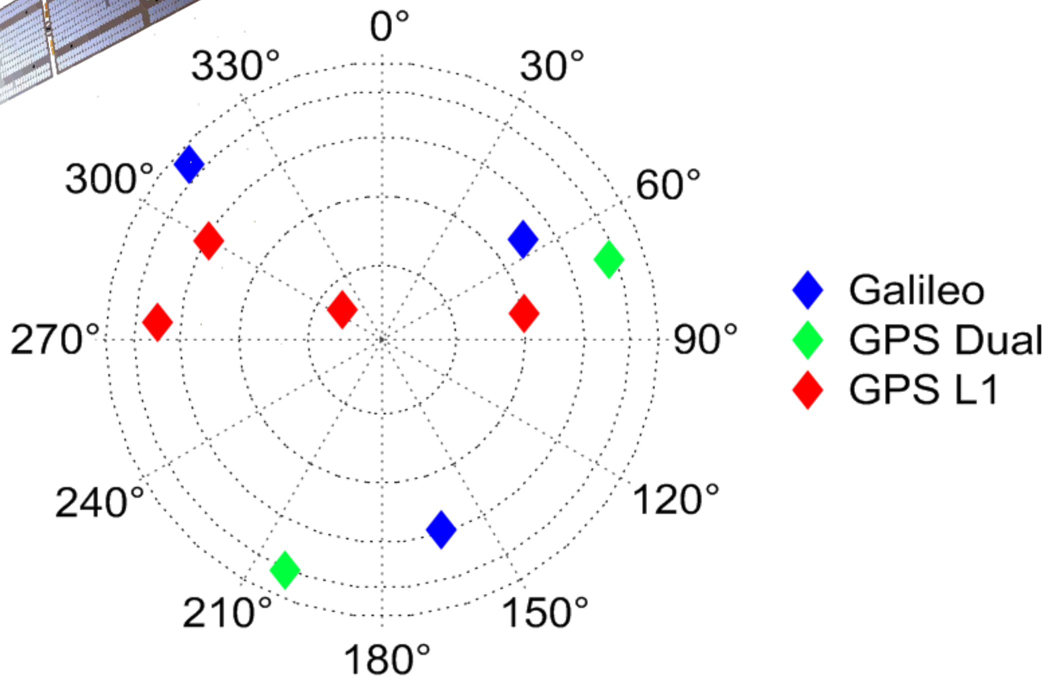
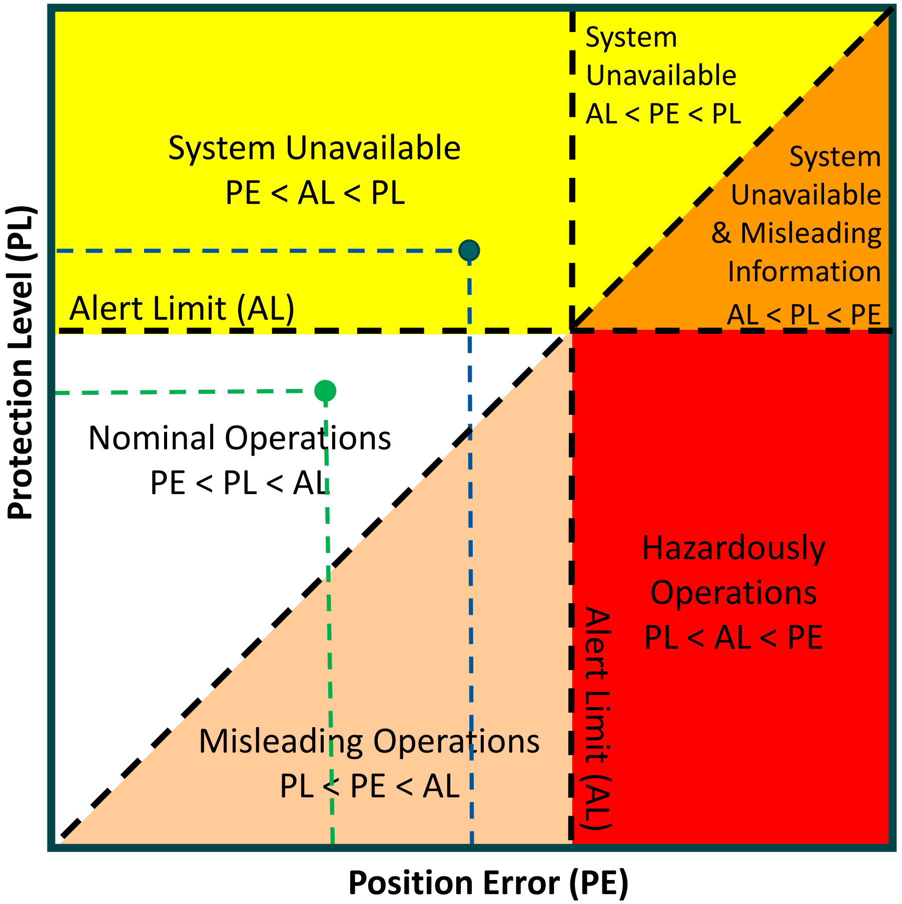


Fig.: Snapshot of a skyplot from a measurement run, Chiemgau 2018

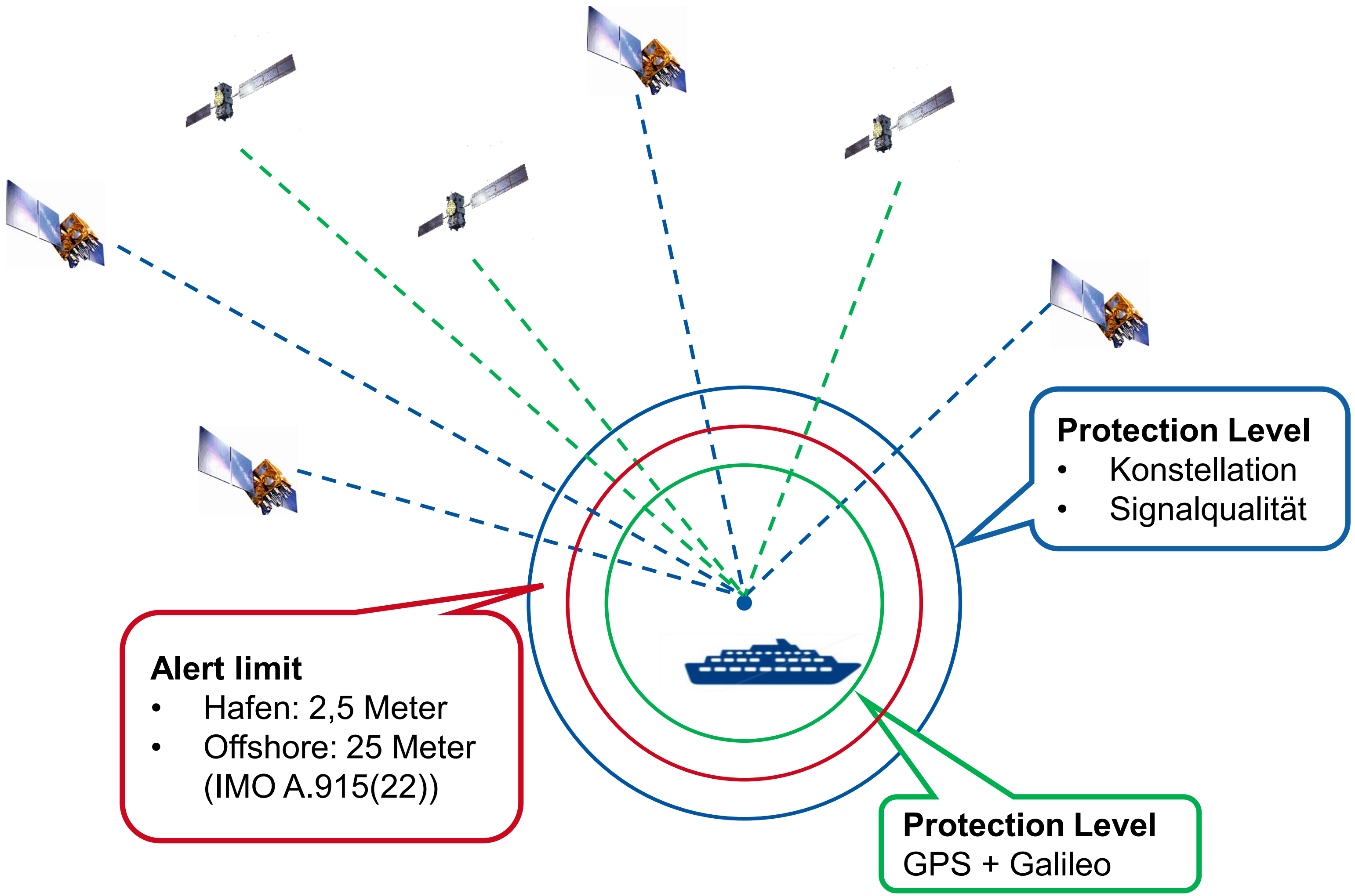
=> Galileo easily can be combined with GPS

Increased availability of integrity statements with the help of Galileo

Stanford diagram



AL = Alert Limit; PE – Position Error; PL – Protection Level



GALILEOnautic 2: Overview

Autonomous Vessels

Funded Research Project GALILEOnautic

Supported by:
Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

GALILEOnautic 2

Autonomous Navigation and Optimal Maneuvering of Cooperative Ships within Safety-Critical Areas
10/2018 – 09/2021

Main objective

Development of a networked and cooperative demonstrator to show the potential of autonomous navigation and optimal maneuvering

GALILEOnautic 2

Project Partners (left) and Associated Partners (right)

Universität Bremen
Online-Capable Optimal Control for Networked Maritme Systems

SCISYS
Optimized Data Transmission and Connected External Services

Hochschule Wismar – University of Applied Sciences Technology, Business and Design
Assisted Ship Navigation and Maneuvring; autom. Docking

RWTH Aachen University
Reliable Localization and Control of Maritime Systems within Networks

TRENZ
Maritime Information Platform

Universität Rostock
Robust and Fault-Tolerant Ship Control

Raytheon Anschütz
Bridge Development for Automatic Vessels

BSH – Bundesamt für Seeschifffahrt und Hydrographie

in – innovative navigation

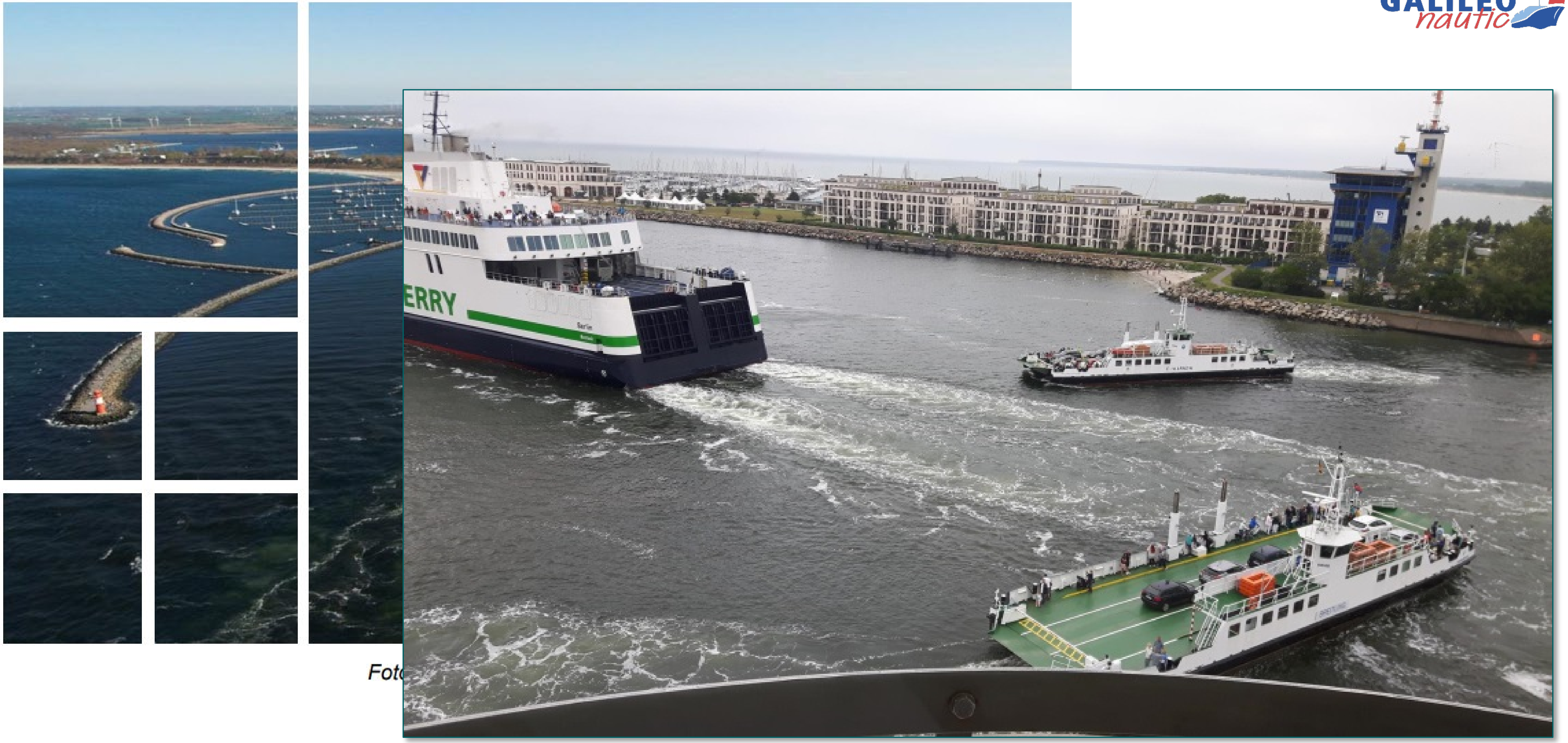
Scandlines

OFFIS

ATLAS ELEKTRONIK

Hafenlotsen-gesellschaft Bremerhaven

Development area Rostock Harbor and a "normal" encounter situation



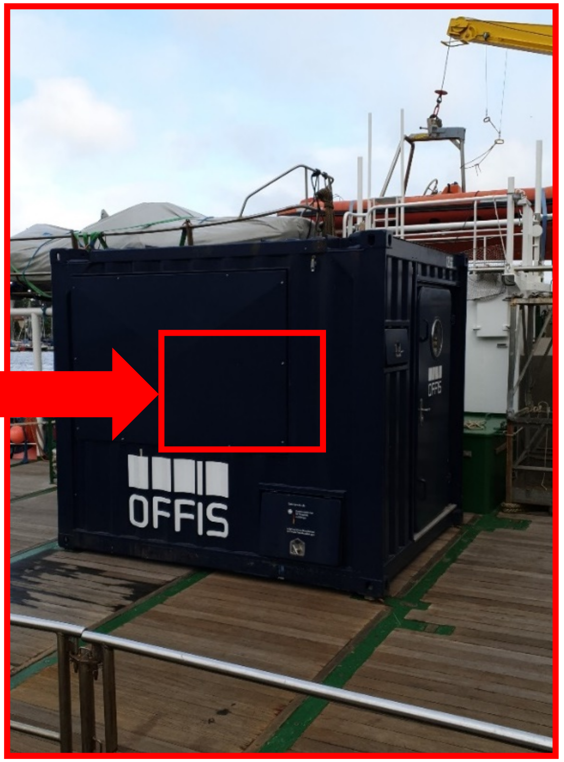
Fot

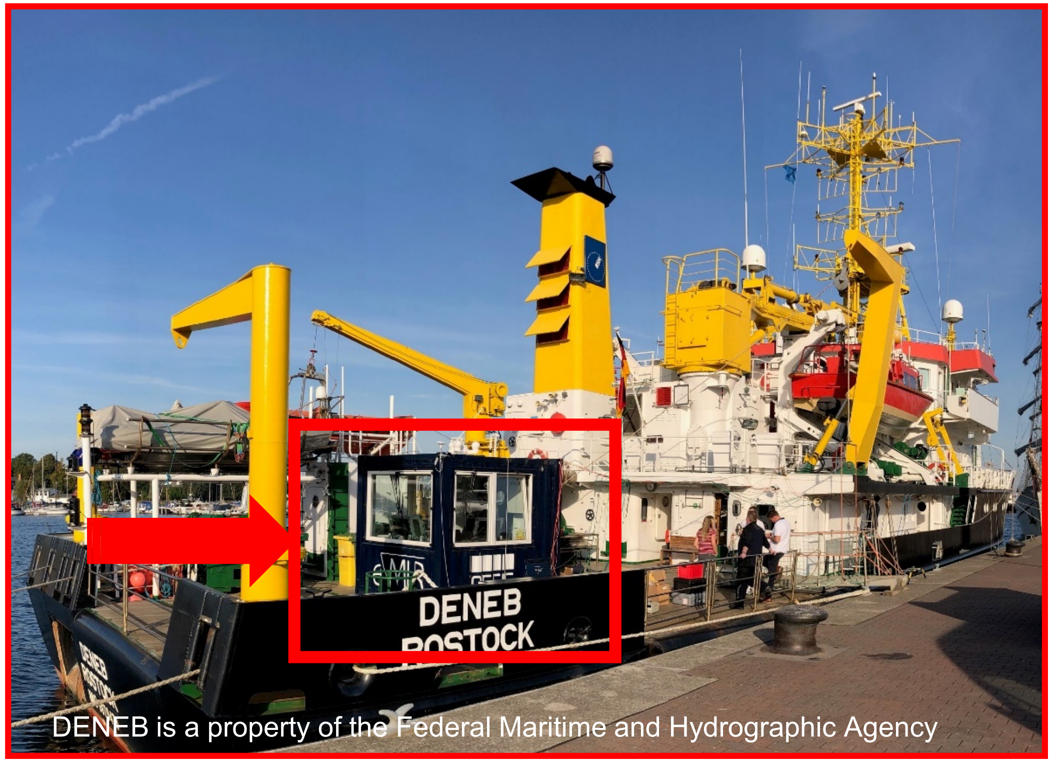
Foto Michael Gluch – HS Wismar

GALILEOnautic 2: Automated Docking with VWFS DENEB

Foto Jiaying Lin – RWTH Aachen

GALILEOnautic 2: Demonstrator setup





DENEB is a property of the Federal Maritime and Hydrographic Agency

VWFS DENEB facts

- In operation for the Bundesamt für Seeschifffahrt und Hydrographie (BSH)
- Operational area Baltic Sea
- Length: 52 Meter; Width: 11 Meter
- Constructed 1994

Hardware for navigation filter

Setup VWFS DENEB

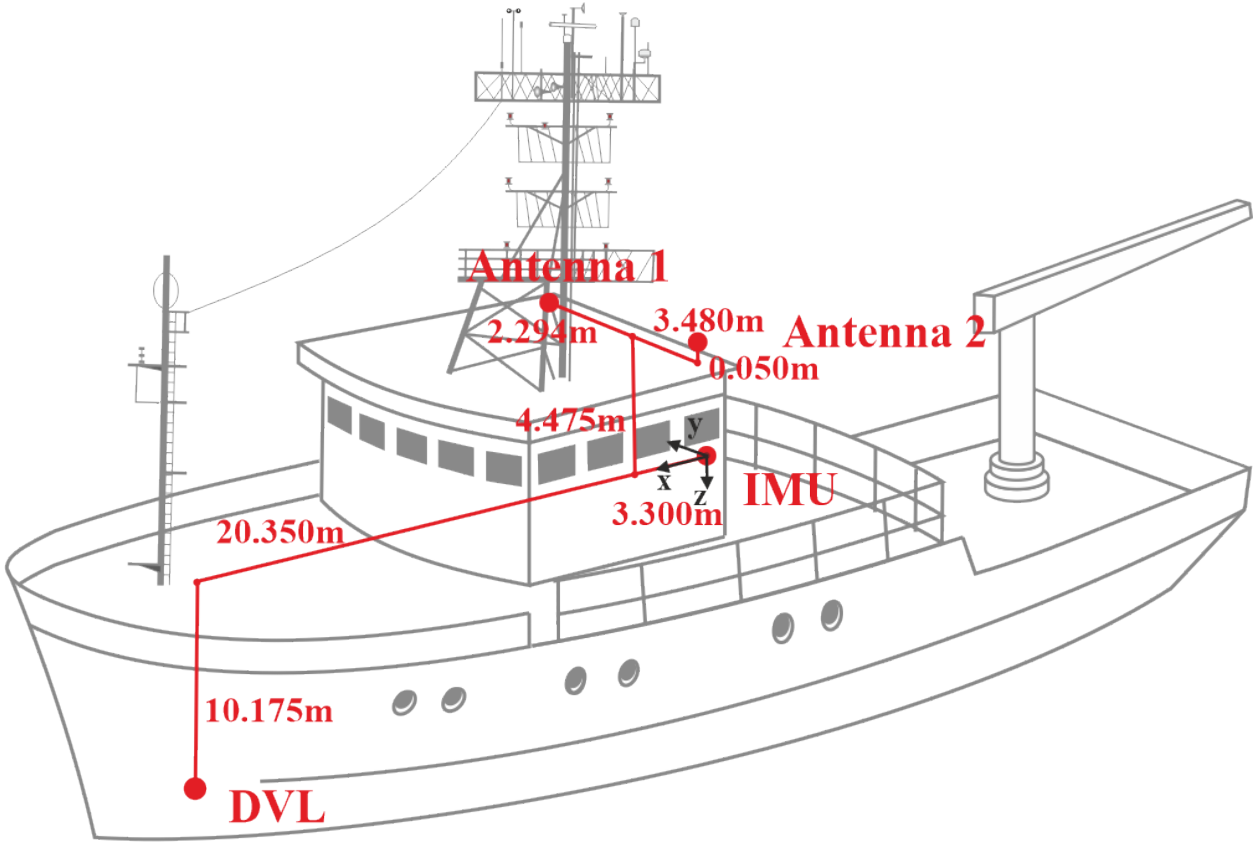
- Multifrequency GNSS receiver

- Industrial-class Intertialsensor

- Doppler Velocity Log

- Real-time, Rapid Control Prototyping unit (single-core 900 MHz)

- Single board computer for real time data access



Entering the port of Rostock: Evaluation of position accuracy

2D driven trajectory of DENEB

First Figure

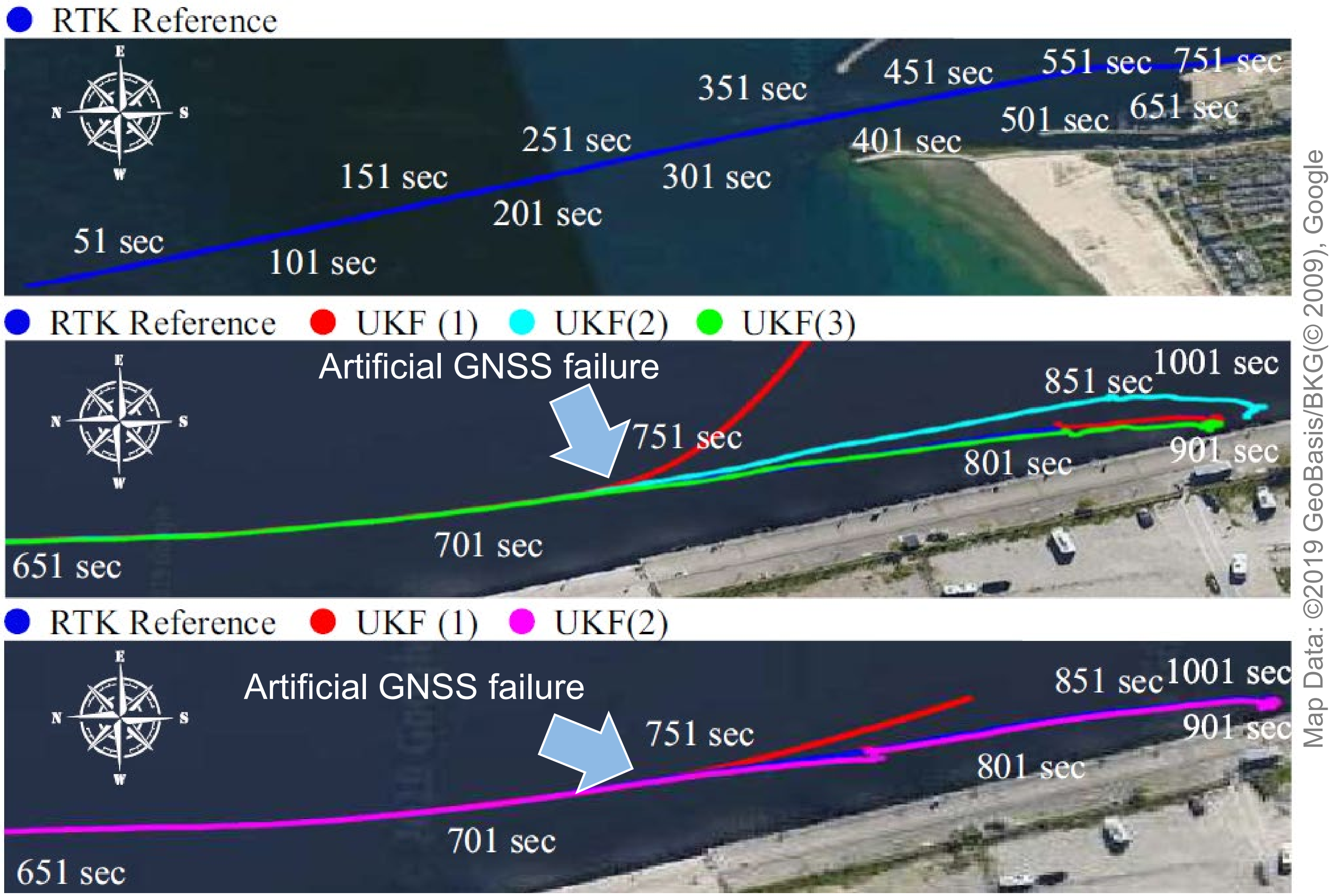
- RTK reference entering the port

Second Figure

- (1): no DVL support
- (2): DVL support without bias st.
- (3): DVL supp. with bias states

Third Figure

- (1): no sea level support
- (2): with sea level support

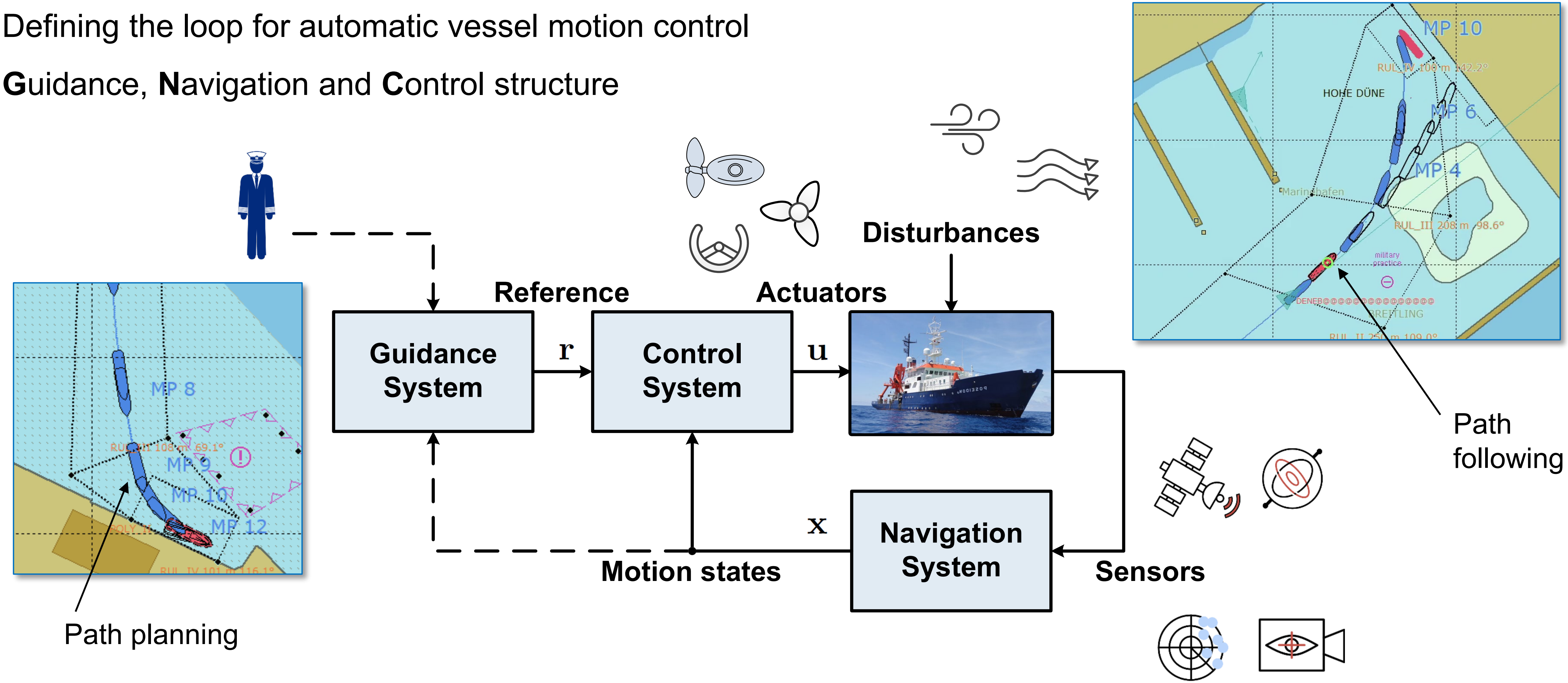


Gehrt, J.-J., et al. (2020): Robust and Reliable Multi-Sensor Navigation Filter for Maritime Application. In: IFAC PapersOnLine 53-2 (2020), pp. 14482–14487.


Towards autonomous operation
(ShipInsight.com)

Integrating the ships GNC system (1)

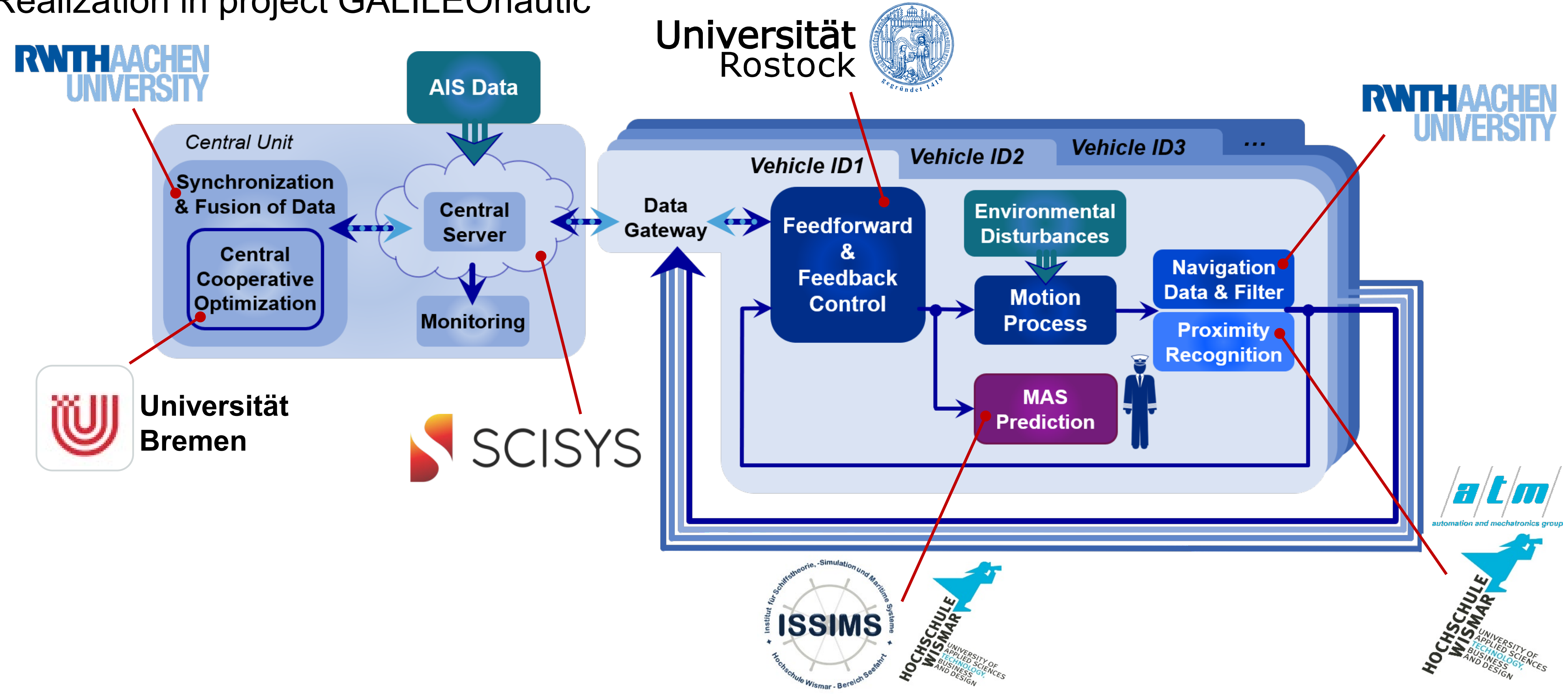
- Defining the loop for automatic vessel motion control
- **G**uidance, **N**avigation and **C**ontrol structure



Kurowski, M., Schubert, A., Jeinsch, T. (2020): Automated Maneuvering in Confined Waters using Parameter Space Model and Model-based Control. In Proceedings of the 21st IFAC World Congress July 12-17, 2020, Berlin, Germany (Virtual), pp. 1-6. DOI: 10.1016/j.ifacol.2020.12.1452

Integrating the ships GNC system (2)

Realization in project GALILEOnautic



Zweigel, R.; Gehrt, J.J.; Liu, S.; Roy, S.; Büskens, C.; Kurowski, M.; Jeinsch, T.; Schubert, A.; Gluch, M.; Simanski, O.; Pairet-Garcia, E.; Siemer, F.; Abel, D. (2019): Optimal Maneuvering and Control of Cooperative Vehicles as Case Study for Maritime Applications within Harbors. In: Proc. of 17th European Control Conference (ECC), Naples, Italy, pp. 3022-3027

Integrating the ships GNC system (3)

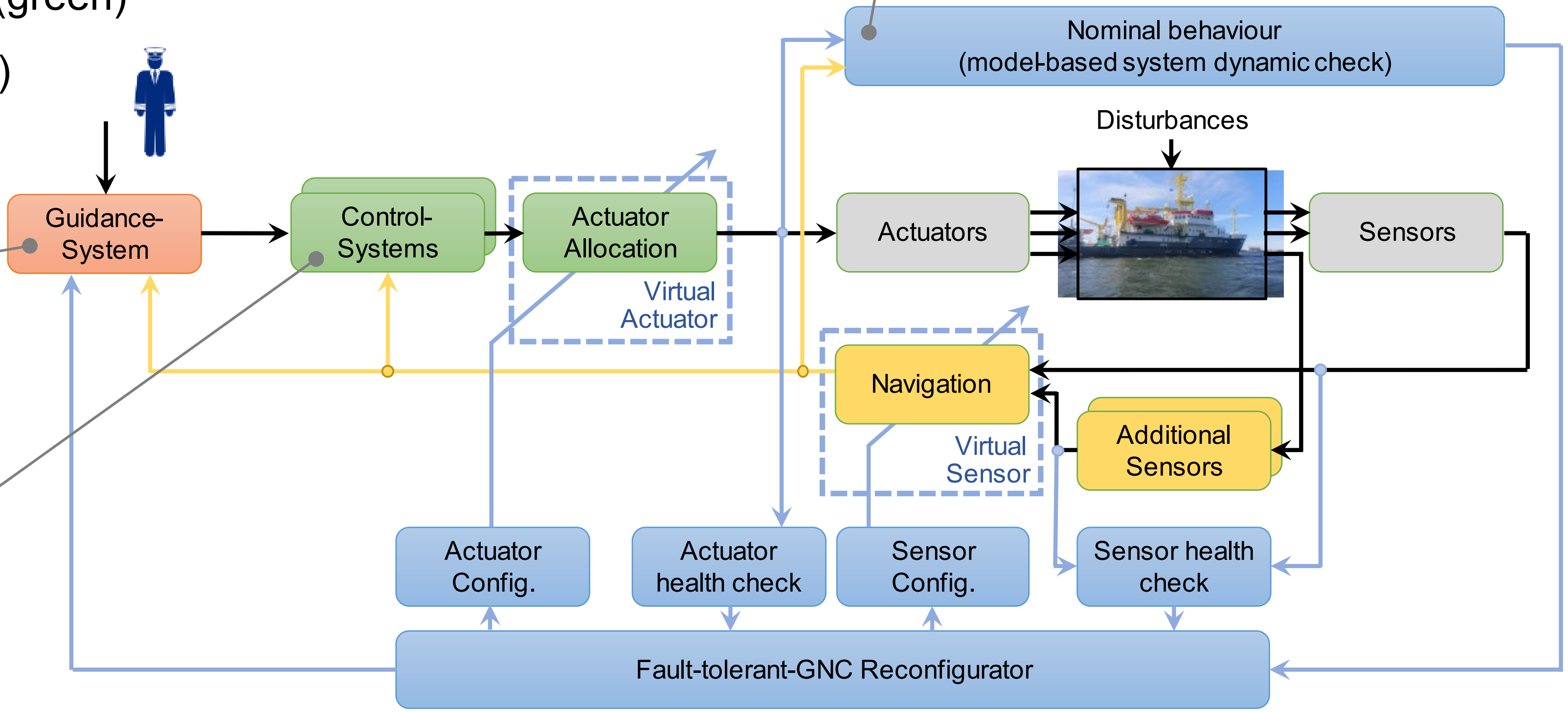
Reliable GNSS-based navigation module as enabler for highly automated operation

- Enhanced parameter identification for model-based designs
- High performance assistance systems (e.g. MAS)
- Input for Guidance (red) and Control (green)
- Input for fault handling modules (blue)

Model-based design of fault handling module

Planning and prediction, e.g. using Maneuver Assistance System (MAS)

Applying optimal controllers



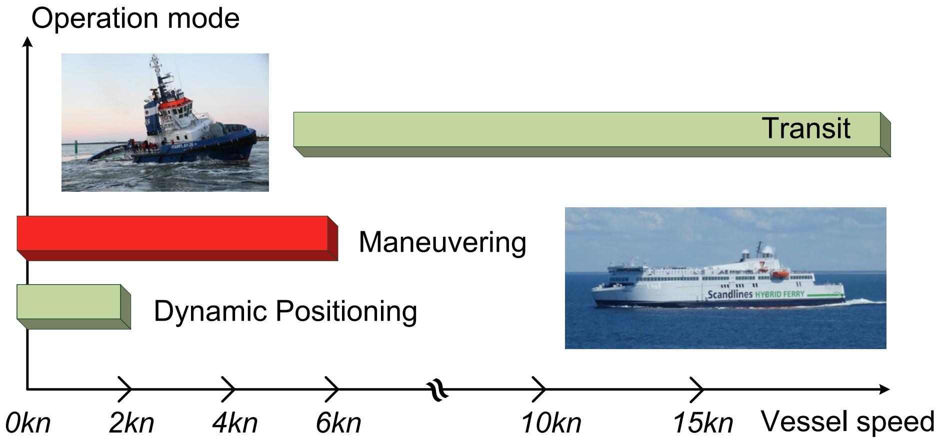
Schubert, A., Kurowski, M., Gluch, M., Simanski, O., Jeinsch, T. (2018): Manoeuvring Automation towards Autonomous Shipping. in Proceedings of the International Ship Control Systems Symposium, Glasgow, UK, October 2-4, 2018, pp. 1-8. DOI: 10.24868/issn.2631-8741.2018.020

Enhanced parameter estimation

GALILEOnautic → focus on harbor scenarios

Challenges

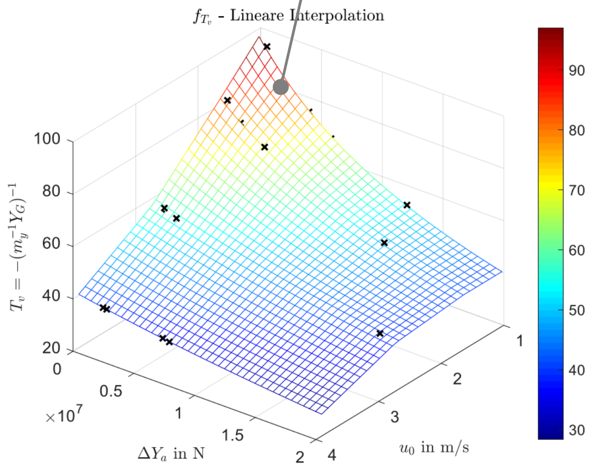
- Complex motions using all available actuators
- High demands for measuring / estimating the motion states
- Missing automation solutions for maneuvering



Change of vessel dynamics (eigenvalues)

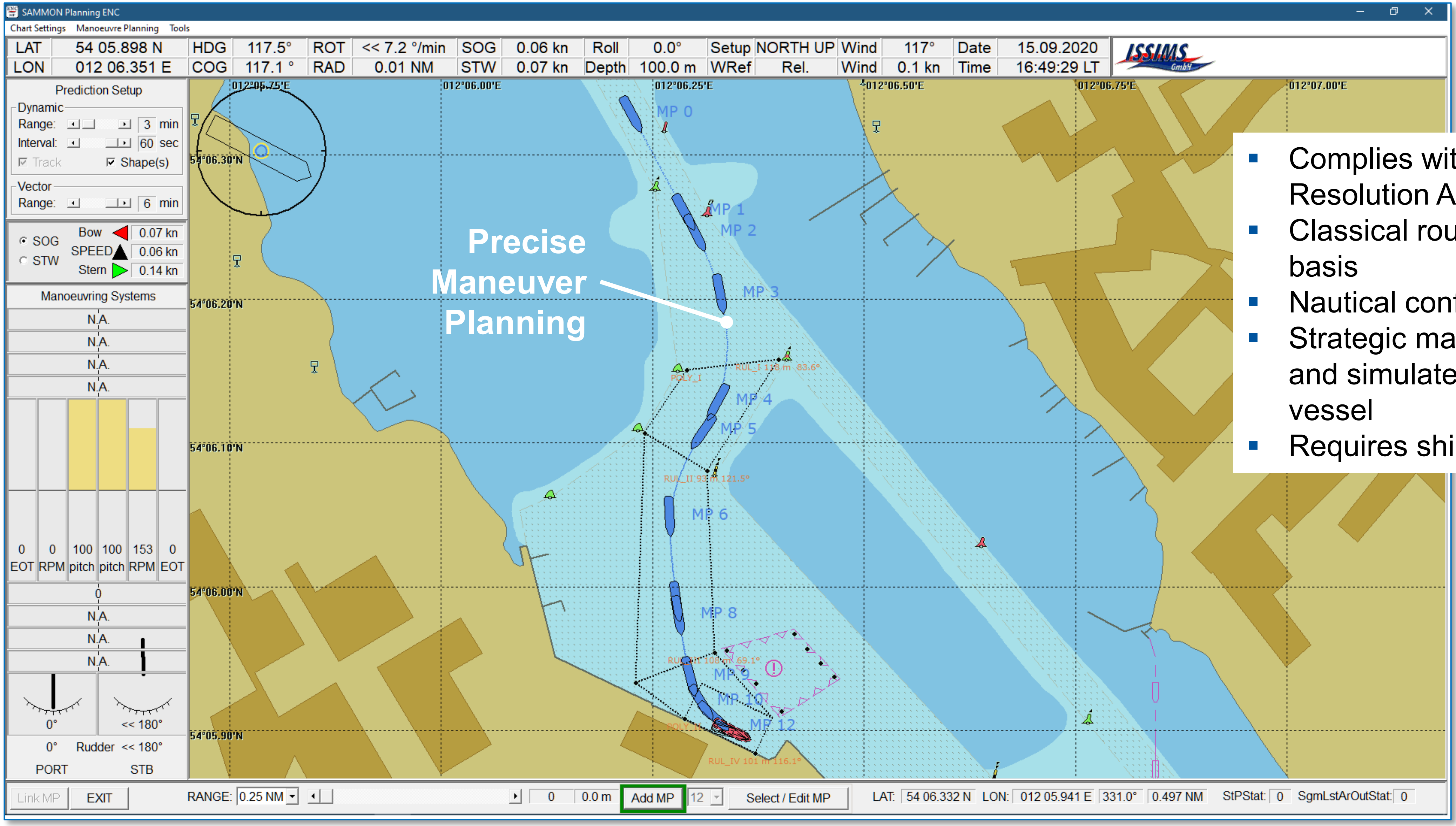
Enhanced parameter estimation due to accurate position information

- Mitigation of the influence of variance of acoustic sensors and accelerometers



Majohr, J., Kurowski, M.: Maritime Regelungs- und Sensorsysteme: Automatisierte Schiffsführung - mit MATLAB® und Simulink®. Springer Vieweg, Wiesbaden, 2021, DOI: 10.1007/978-3-658-31721-8.

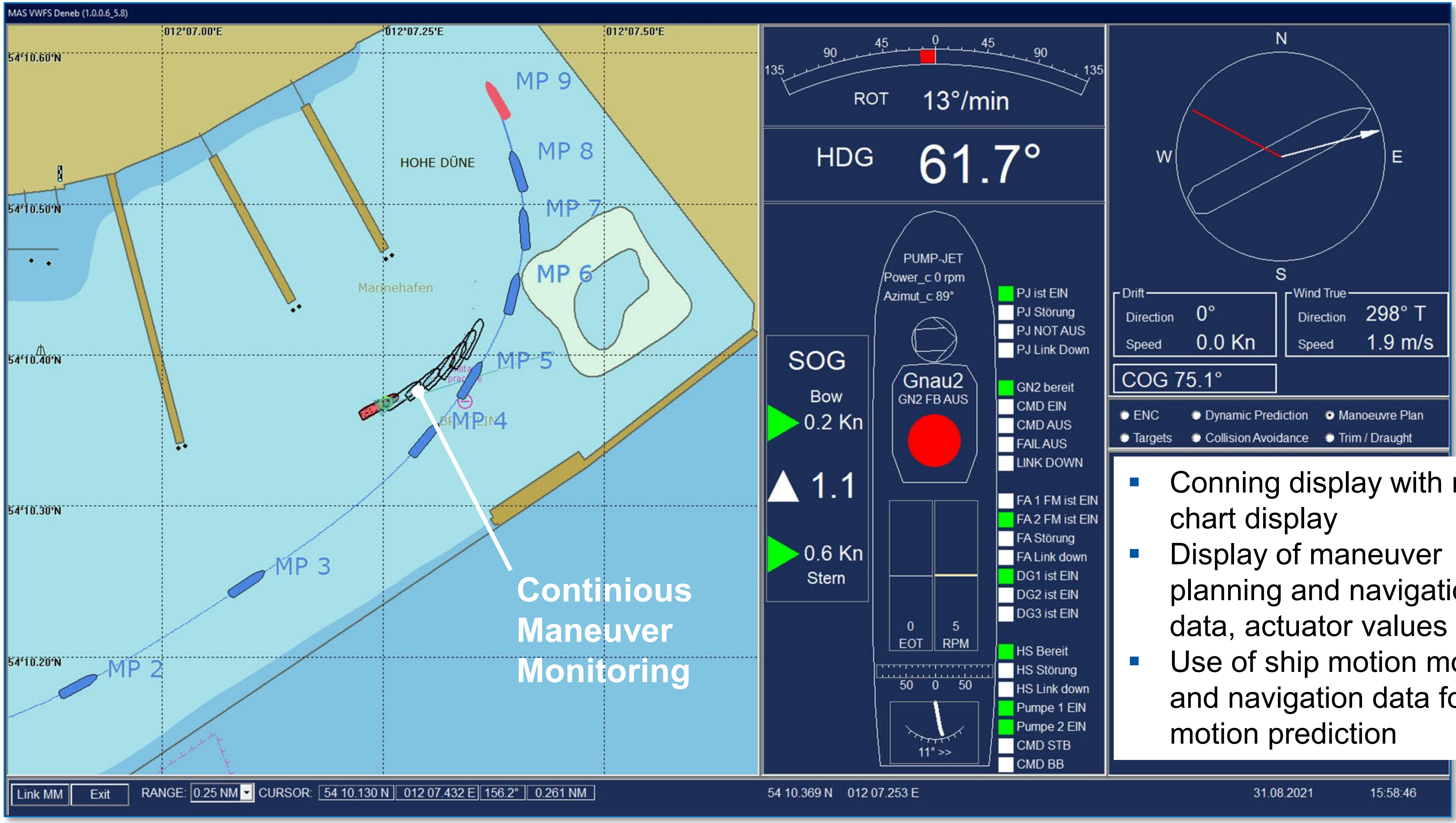
Maneuver Assistance System (1)



- Complies with IMO Resolution A. 893(21)
- Classical routes as planning basis
- Nautical conform approach
- Strategic maneuvering points and simulated path of the vessel
- Requires ship motion model

Schubert, A.U., Kurowski, M., Damerius, R., Fischer, S., Gluch, M. Baldauf, M., Jeinsch, T.: From Manoeuvre Assistance to Manoeuvre Automation. Journal of Physics: Conference Series, 1357:012006, oct 2019, DOI: 10.1088/1742-6596/1357/1/012006

Maneuver Assistance System (2)



- Conning display with nautical chart display
- Display of maneuver planning and navigation data, actuator values
- Use of ship motion model and navigation data for motion prediction

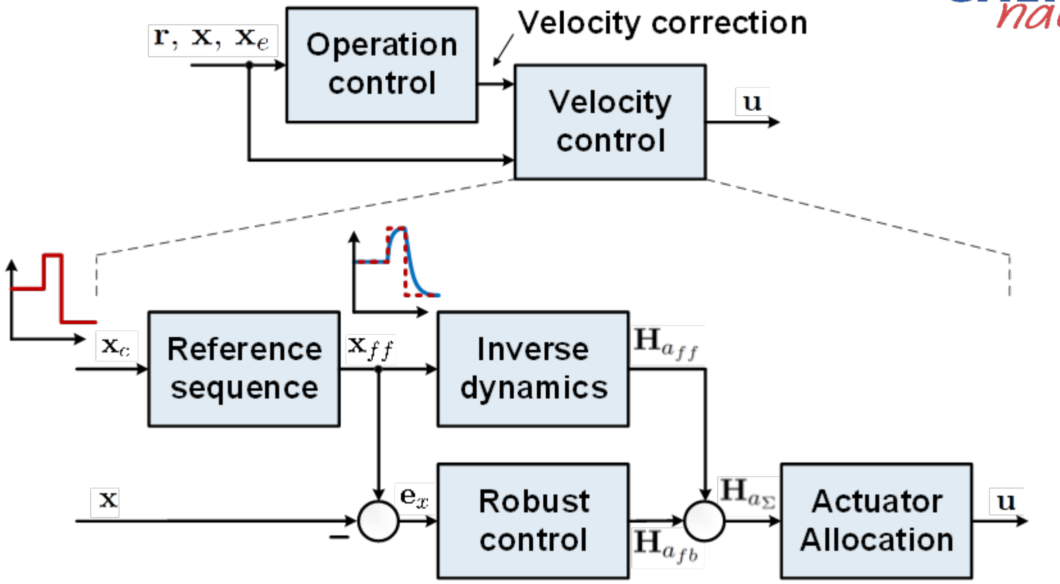
Schubert, A.U., Kurowski, M., Damerius, R., Fischer, S., Gluch, M. Baldauf, M., Jeinsch, T.: From Manoeuvre Assistance to Manoeuvre Automation. Journal of Physics: Conference Series, 1357:012006, oct 2019, DOI: 10.1088/1742-6596/1357/1/012006

Control system design (1)

Generic structure for covering the entire operation range

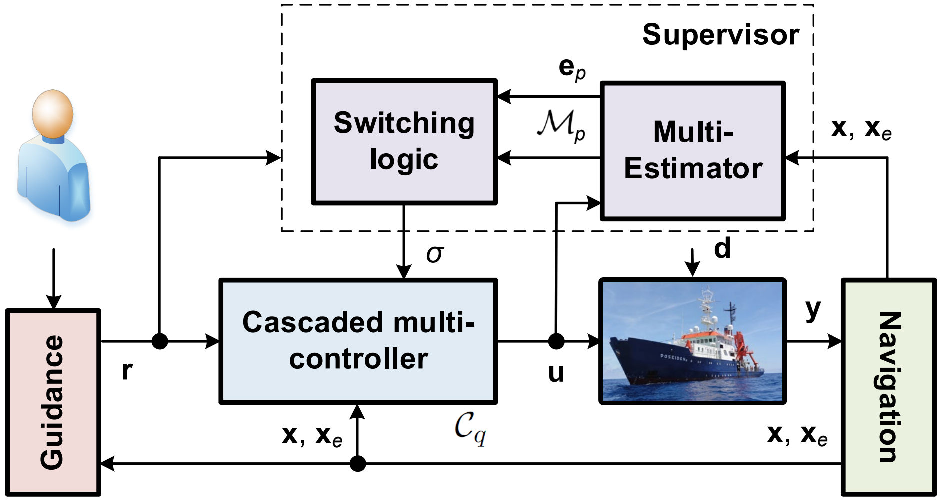
Cascaded multi-controller structure

- 2 DOF control
- Consideration of modeled nonlinearities by feedforward
- Disturbance attenuation by feedback control
- Inline allocation



Hybrid extension

- Set of inner loop controllers
- Set of mission-based controllers (e.g. path following, trajectory tracking or DP)
- Supervisor-based selection of suitable control structure



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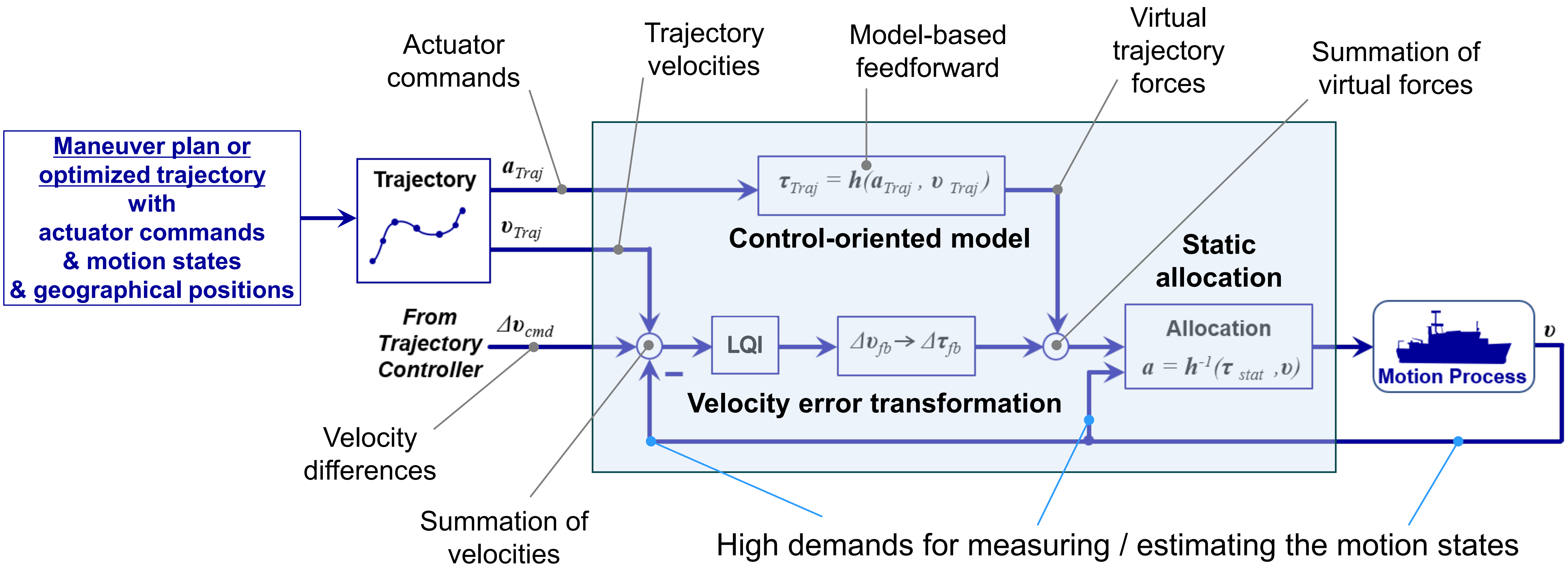
Control system design (2)

Trajectory integration into the model-based control system

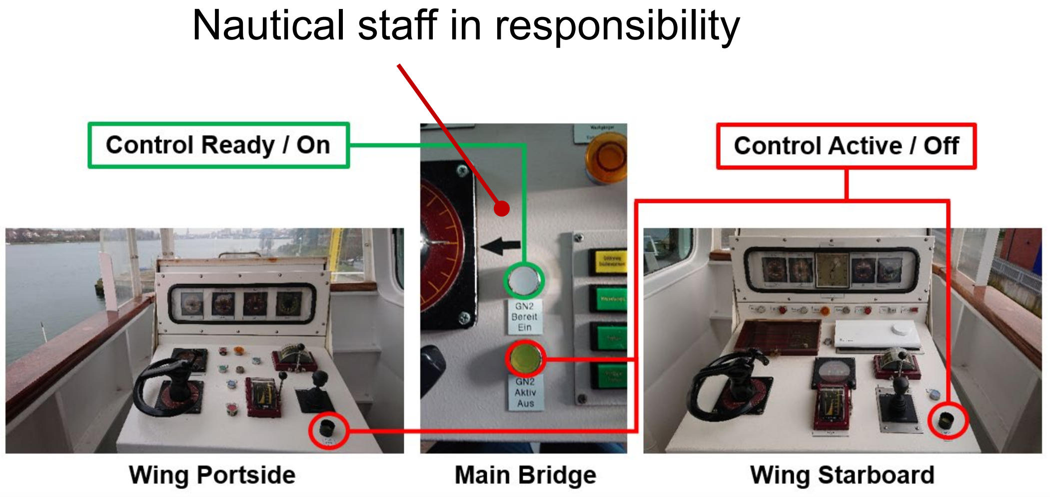


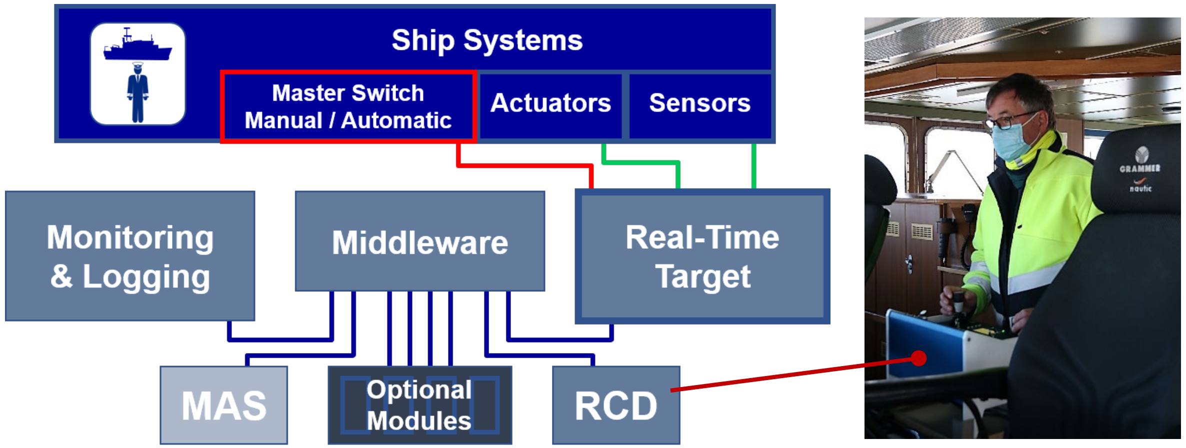
Rethfeldt, C., Schubert, A.U., Damerius, R., Kurowski, M., Jeinsch, T.: System Approach for Highly Automated Manoeuvring with Research Vessel DENEB. In Proc. of the 13th IFAC Conference on Control Applications in Marine Systems, Robotics, and Vehicles (CAMS), 2021.

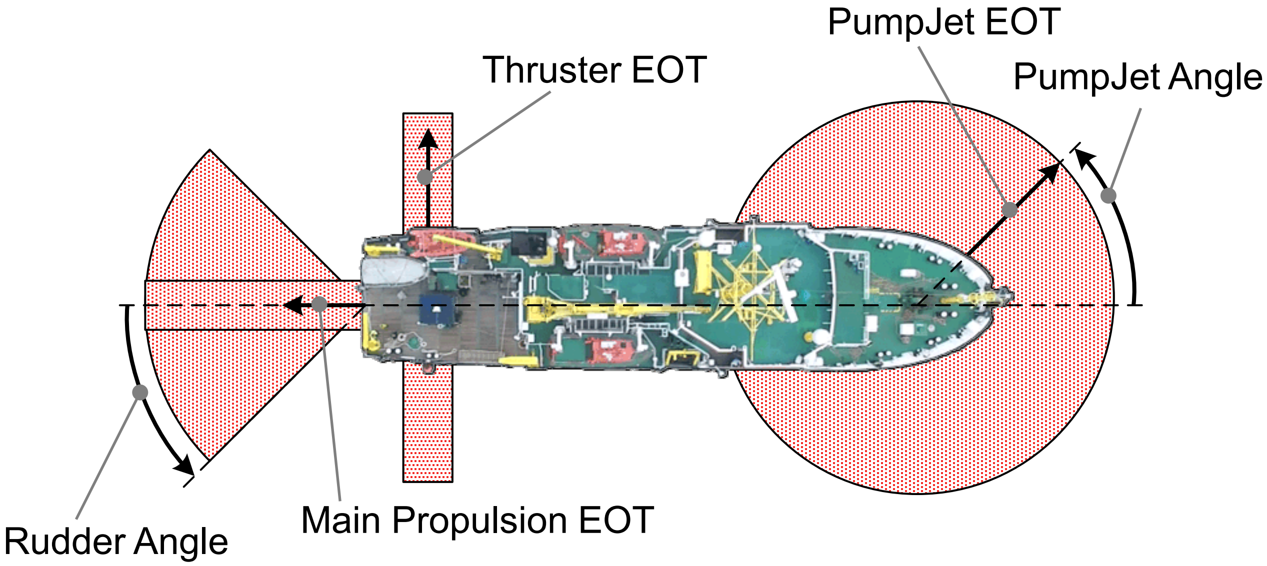
Validation with DENEB (1)

Digitalization and automation of VWFS DENEB

- Digital acquisition of all sensor data
- Digital command of all actuators
- Middleware for connecting the GN2 modules
- Actuator allocation
- Assisting control systems and DP functionalities







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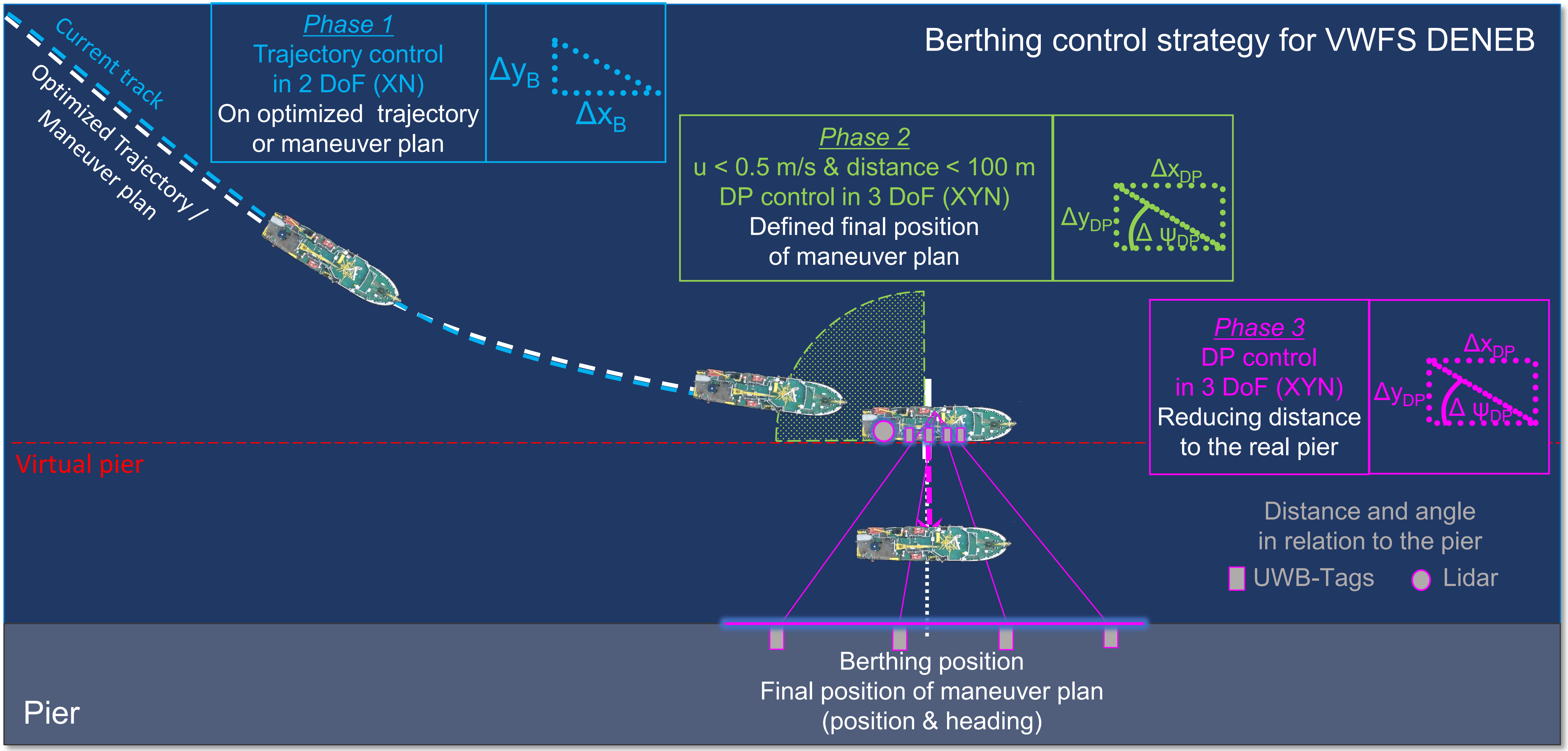
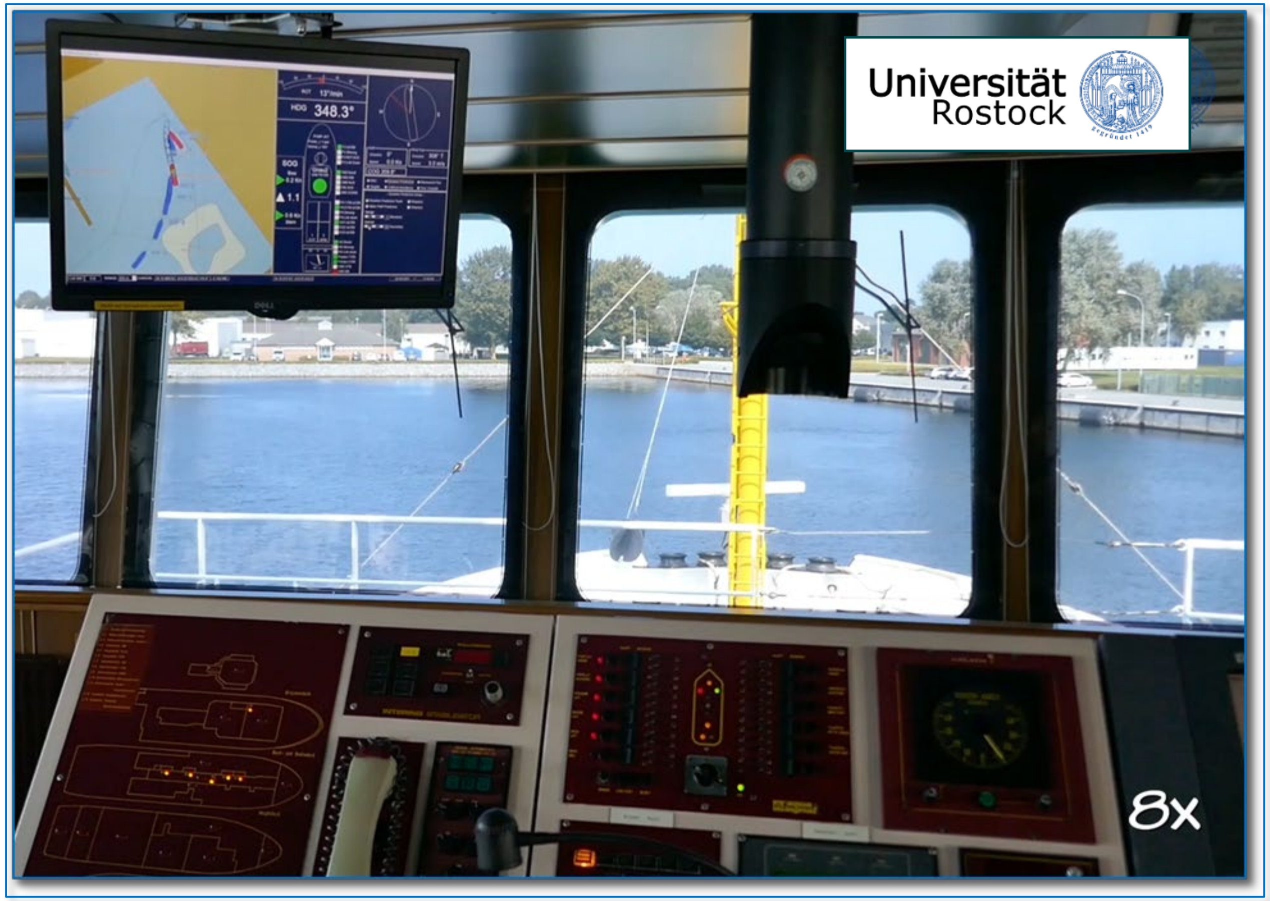
Validation with DENEB (2)



Validation with DENEB (3)

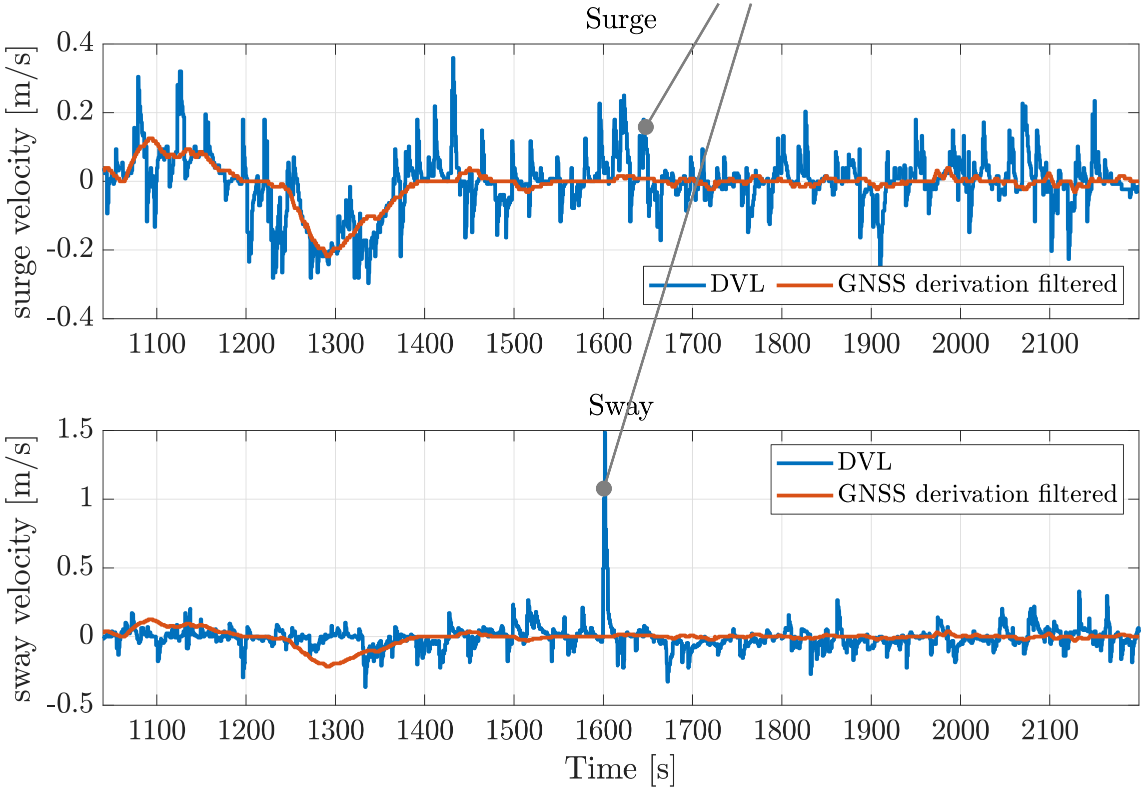
Results from automatic berthing tests (2021/09/02)

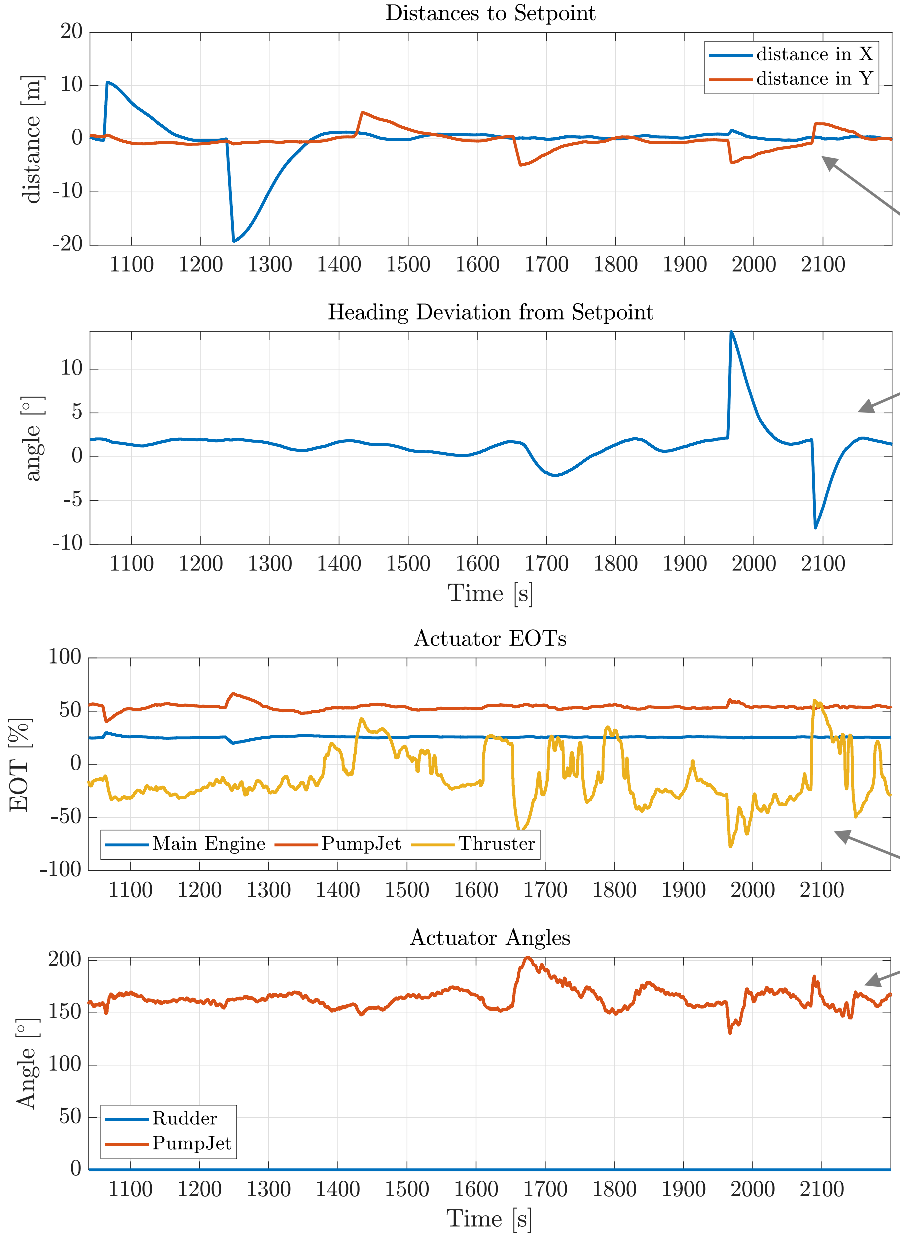


Validation with DENEB (4)

Impact of GNSS based navigation on the control results

Measurements of the Doppler Log





Dynamic Positioning operation of vessel DENEB

Actuating values


Summary & outlook
(ShipInsight.com)

Summary

General findings and insights into GALIEOnautic 2

Advantages of Galileo are exploited in the GALILEOnautic 2 research project to enable automated maneuvering in port areas of the future

From a satellite navigation perspective:

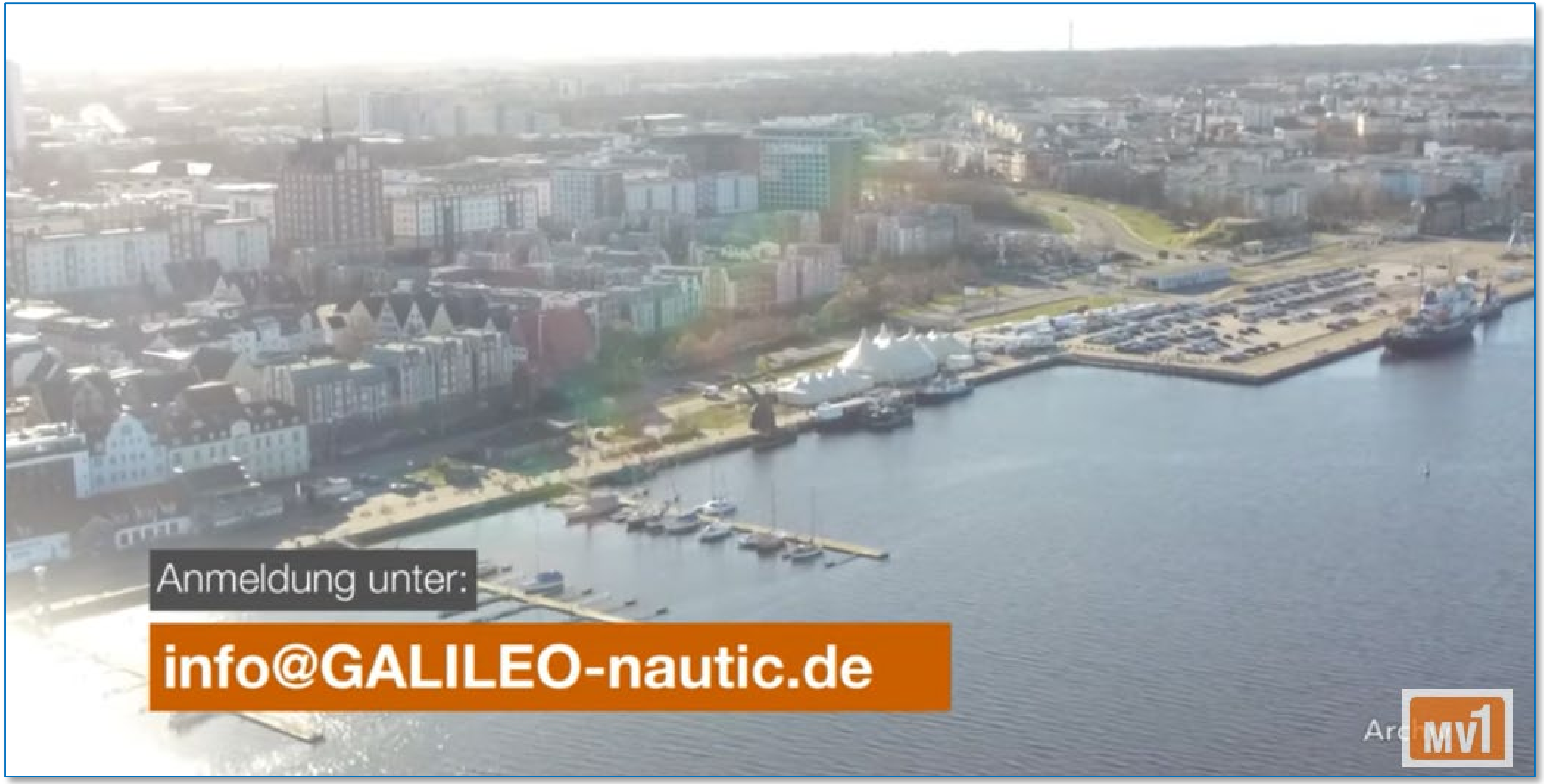
- Galileo helps increase confidence in satellite navigation
- Galileo easily can be combined with GPS
- Using Galileo increases position accuracy
- Galileo improves detection & identification of signal errors

From a GNC perspective:

- Enhanced parameter estimation due to reliable position information
- Mitigation of the influence of variance of acoustic sensors and accelerometers
- Implementation of high performance assistance systems
- Application of optimal Guidance and Control algorithms

GALILEOnautic 2: Final demonstration September 14, 2021

Please watch the announcement on YouTube: www.youtube.com/watch?v=j6GMpvUF3yY



Thank you
for your attention!

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