Fullscale Testing of DP Control Algorithms On R/V Gunnerus Fall 2016

Astrid H. Brodtkorb
Svenn Are Værnø

AMOS days October 28th 2016

Dynamic Positioning in Extreme Seas

PhD Candidate: Astrid H. Brodtkorb

Increasing the operation window of dynamic positioned vessels using hybrid design methods

- Dynamic Positioning (DP) in Extreme Seas
- Hybrid Dynamical Systems
- Modeling and Simulation
- Control and Stability Analysis

Outcomes:
Model- and sensor-based control algorithms in order to improve autonomy and performance in DP operations in extreme environmental conditions.

Supervisor: Asgeir J. Sørensen
Co-supervisors: Andrew R. Teel, Ulrik D. Nielsen, Vahid Hassani, Marilena Greco, Dong Trong Nguyen

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Nonlinear and Hybrid Control Topics for Demanding DP Operations

PhD Candidate: Svenn Are Værnø

Control of dynamic positioning of vessels in extreme seas and harsh environment.

- Control design
- State estimation

Outcomes:

- Nonlinear design methods
- Hybrid design
- Simulations, experiments

Supervisor: Professor Roger Skjetne
Co-supervisor: Professor Asgeir Sørensen

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Outline

- Part 1: Who, what and how
- Video
- Part 2: NTNU algorithms

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KM/NTNU Collaboration

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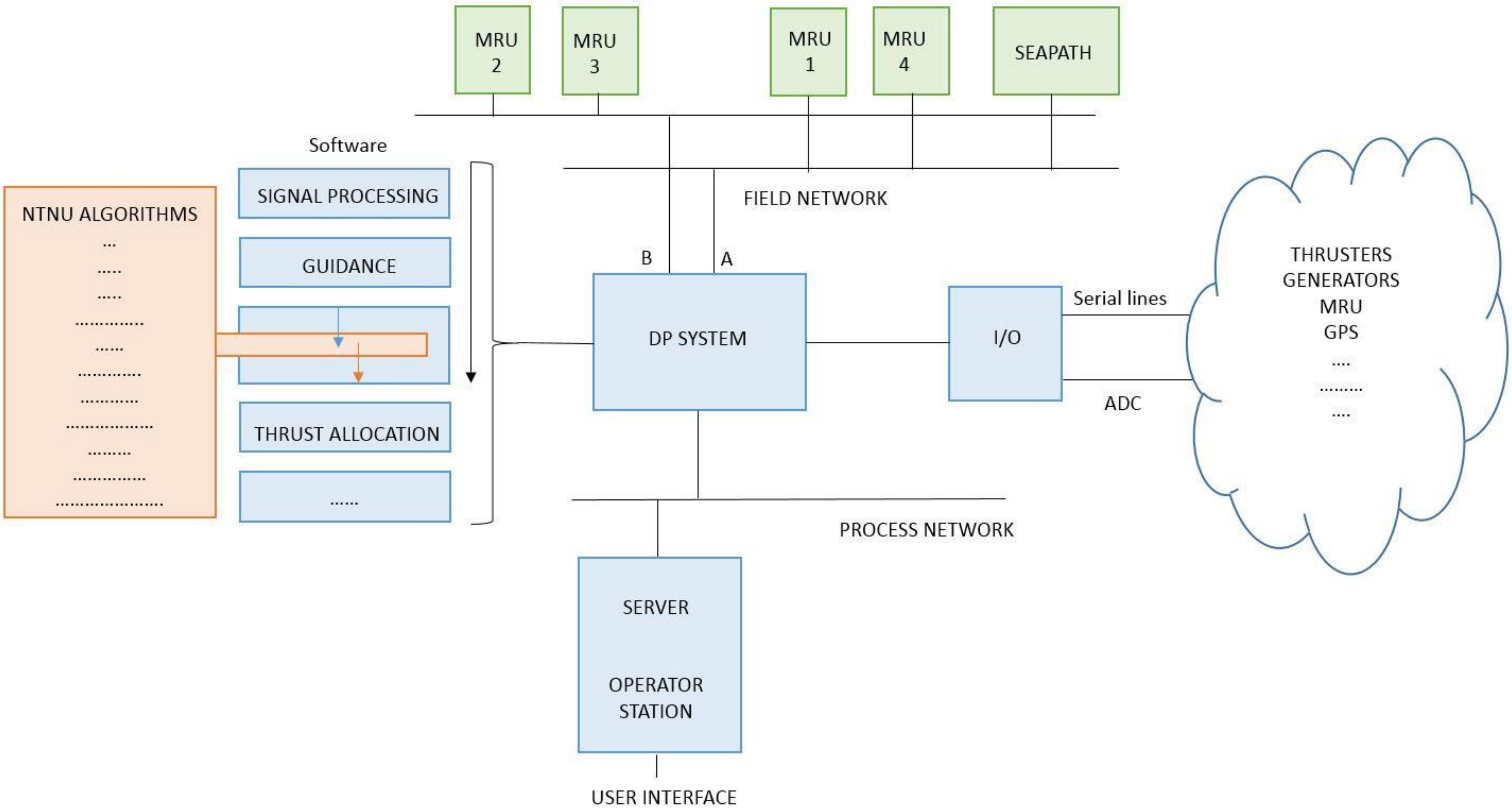
KM DP Test Interface



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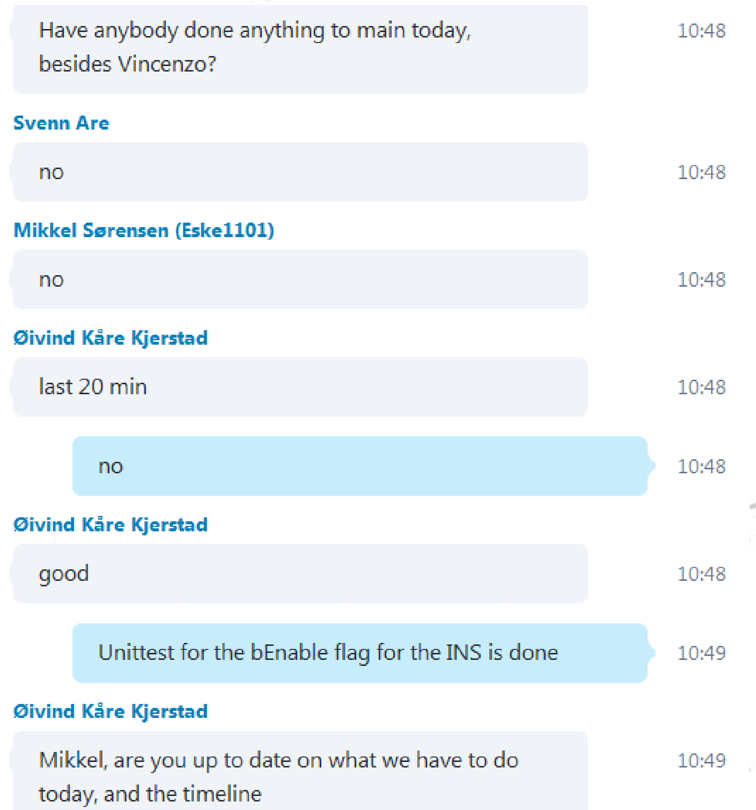
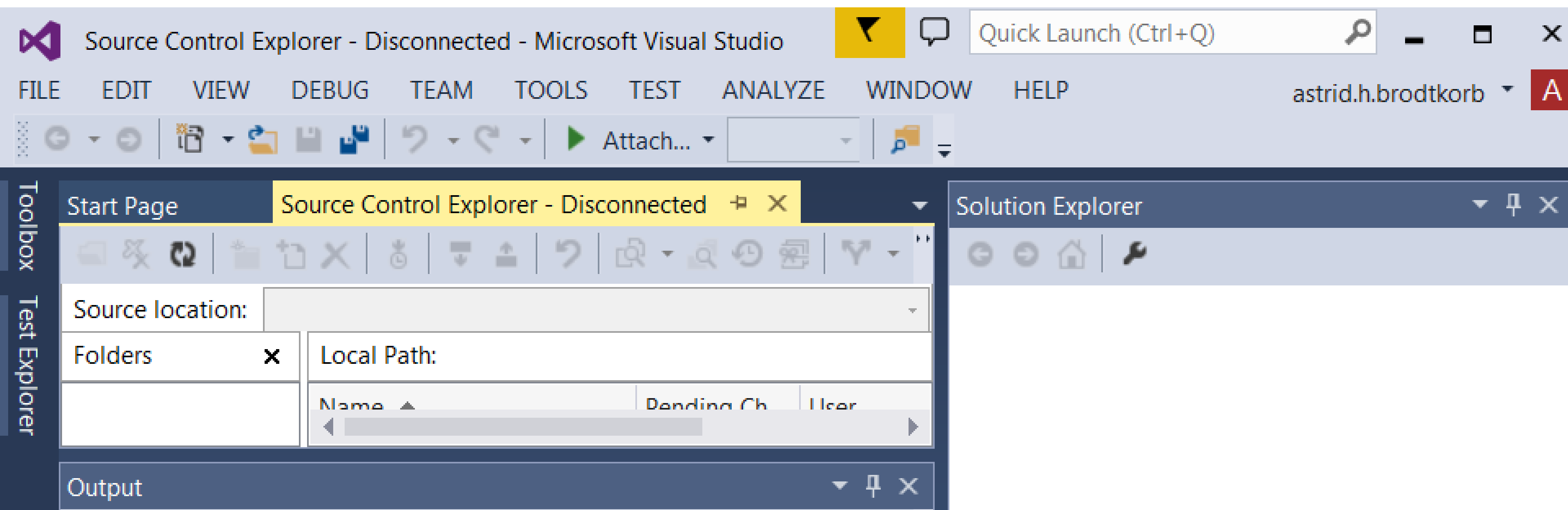
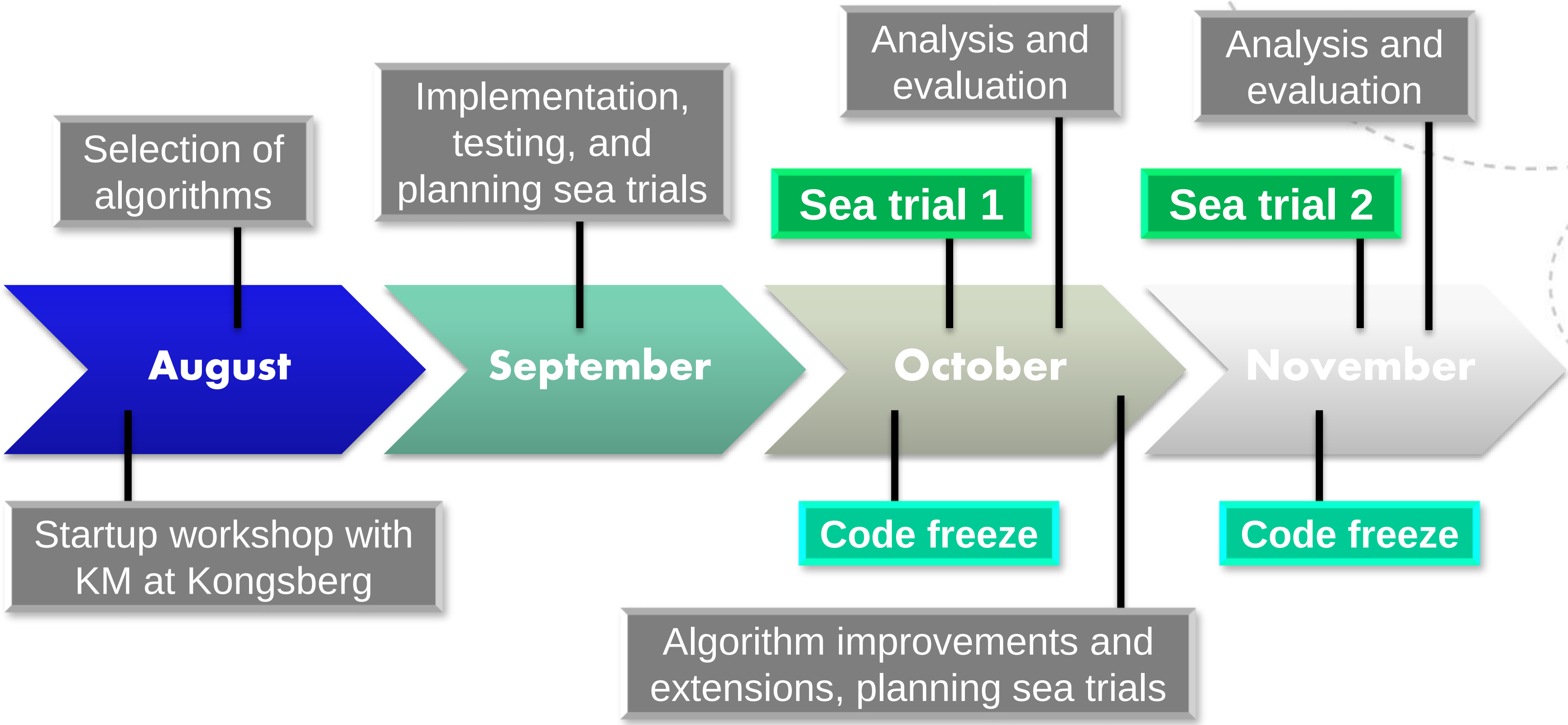
Coding

- VPN connection to KM server
- MS Visual Studio
- Skype chat
- Regular meetings





Timeline



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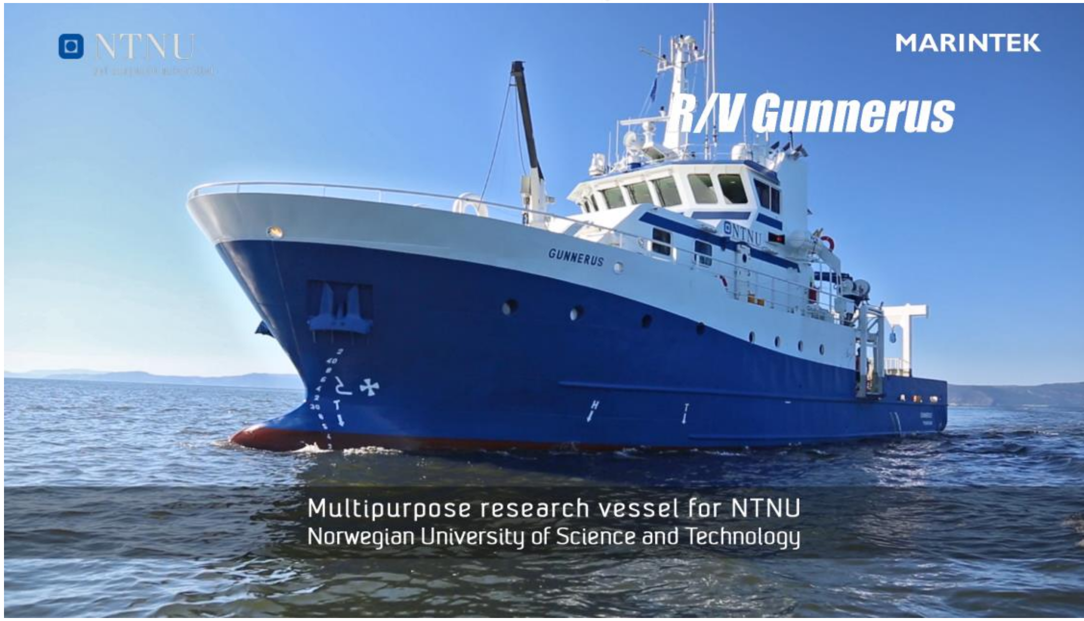
R/V Gunnerus

- 31 m long research vessel
- Owned by NTNU
- Equipment: trawl winches, deck crane, container attachment
  - used of ROV operations
- Wet lab, dry lab and computer lab
- Main propulsion: RR azimuthing thrusters
- Brunvoll tunnel thruster



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Video

Thanks to Mikkel Sørensen for compiling…

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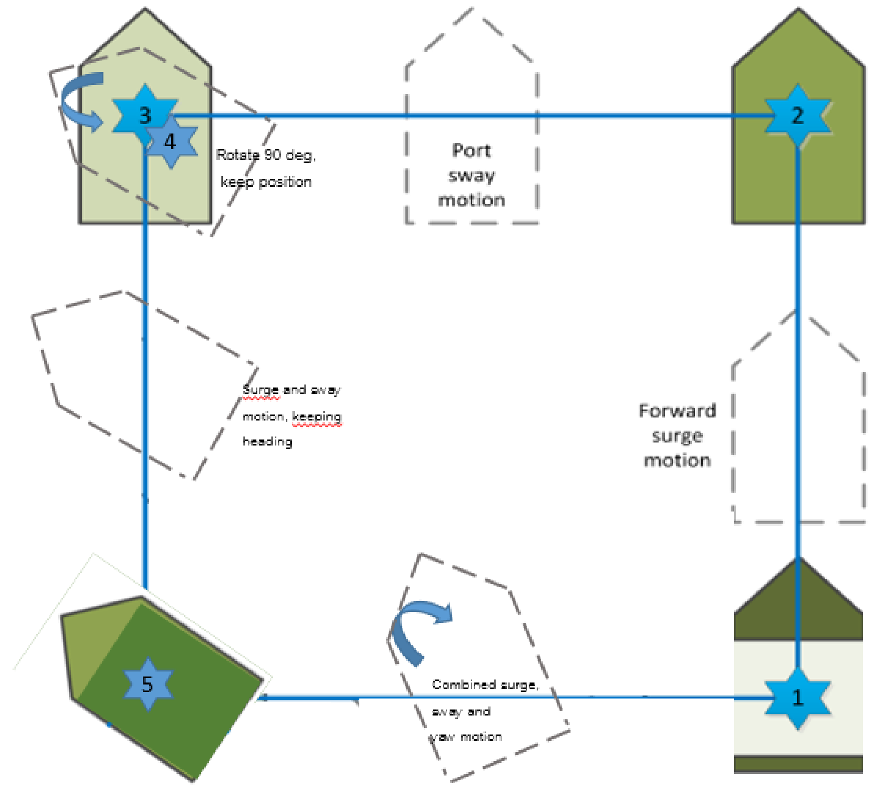
Part 2: NTNU Tests

- October 17th-21st
- 3 days, 10 algorithms
- 4 corner test



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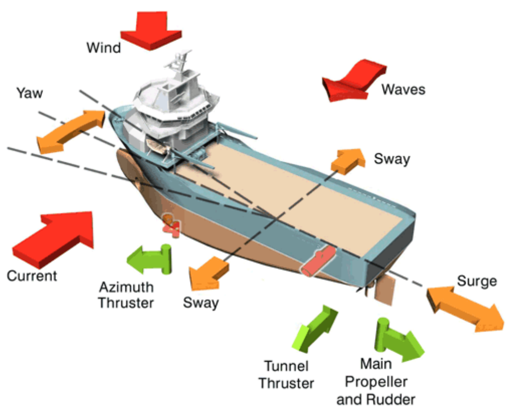
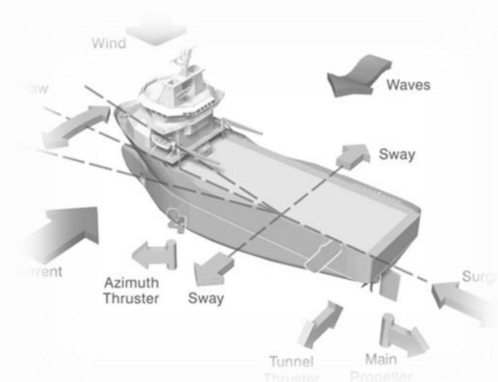
Marine Vessel Modeling

Real world



Courtesy: Kongsberg Maritime

Model



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Marine Vessel Modeling

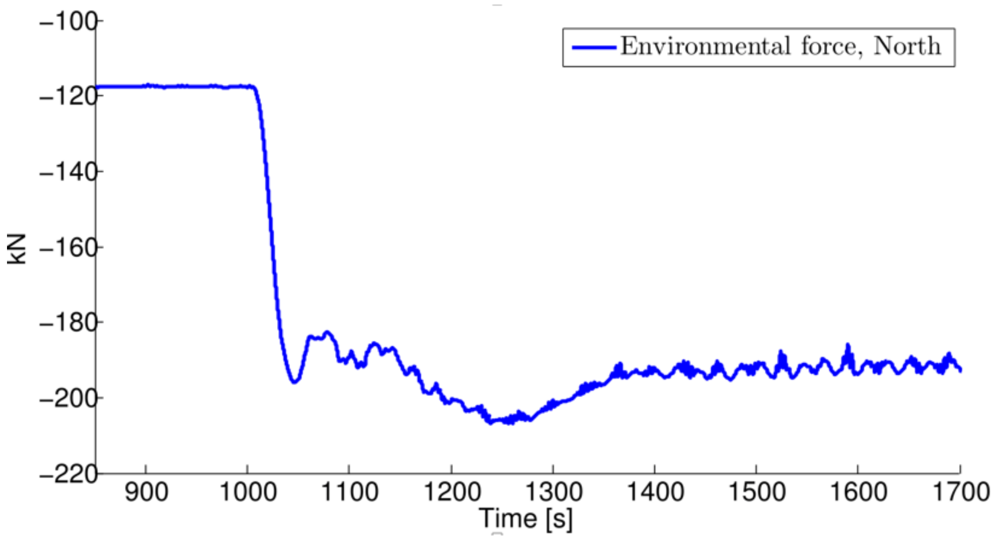

Fig: Env. Force (North). Heading change 90 degrees at 1000 seconds.

Vessels experience transient response due to the operation taking place

- e.g. heading change

or from the environment

- e.g. wave trains, varying current direction

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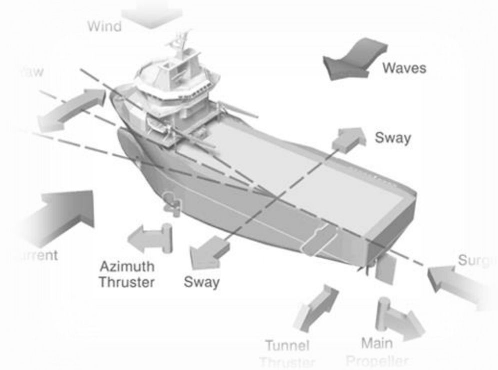
Marine Vessel Modeling

Model

- First order wave frequency vessel motion

- Heading-dependent forces and moments from waves, wind and current



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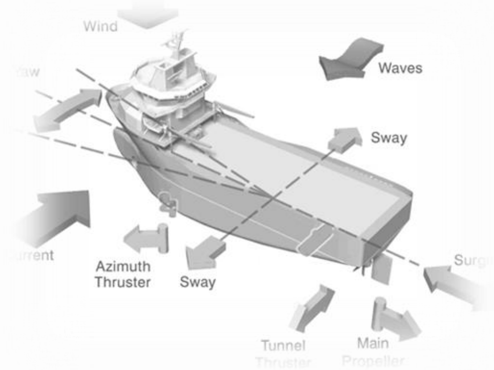
Marine Vessel Modeling

- Control plant model (design model)
  - Simplified vessel dynamics
  - Environmental force model
  - 3 DOF for surface DP vessel
  - Separates low frequency and wave frequency motion

- Kinematic (or strapdown) model
  - Acceleration, velocity, position
  - 6 DOF
  - Total vessel motion

Model



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Hybrid Signal-based and Model-based observer

(Astrid H. Brodtkorb)

- Control plant model → Model-based observer
  - Simplified vessel dynamics
  - Environmental force model
  - 3 DOF for surface DP vessel
  - Separates low frequency and wave frequency motion

- Kinematic (or strapdown) model → Signal-based observer
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Hybrid Signal-based and Model-based observer

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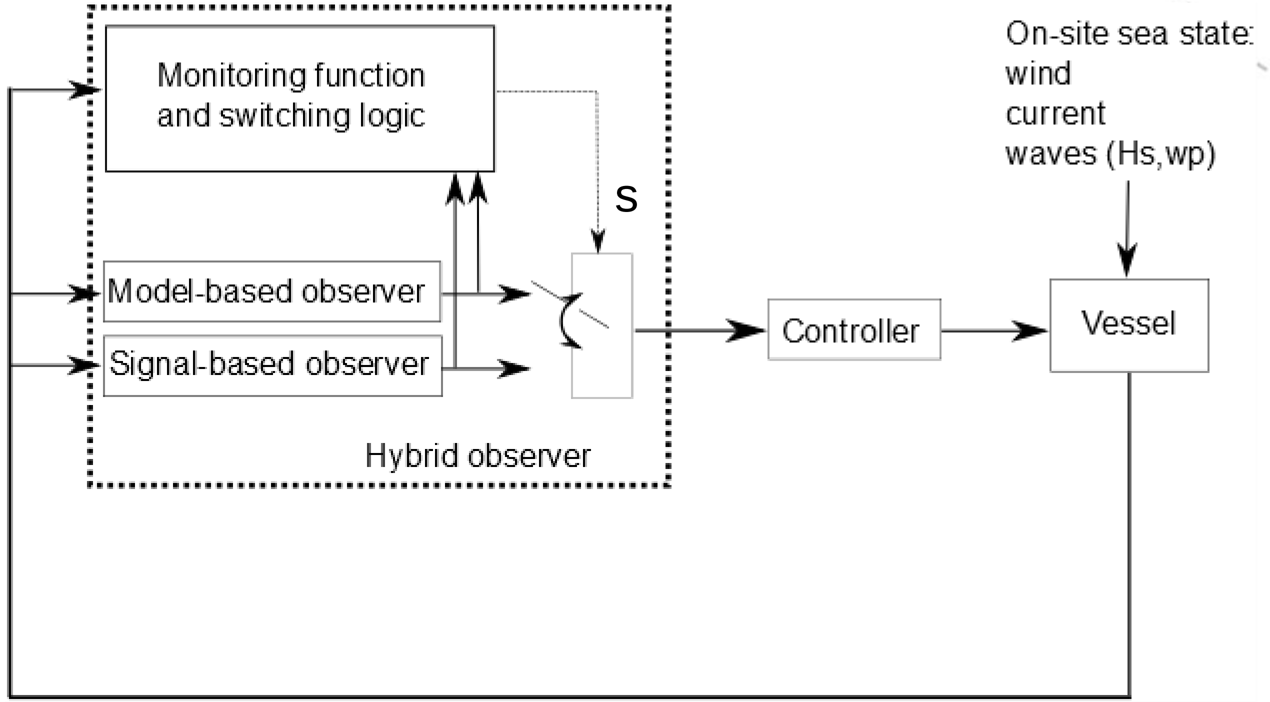


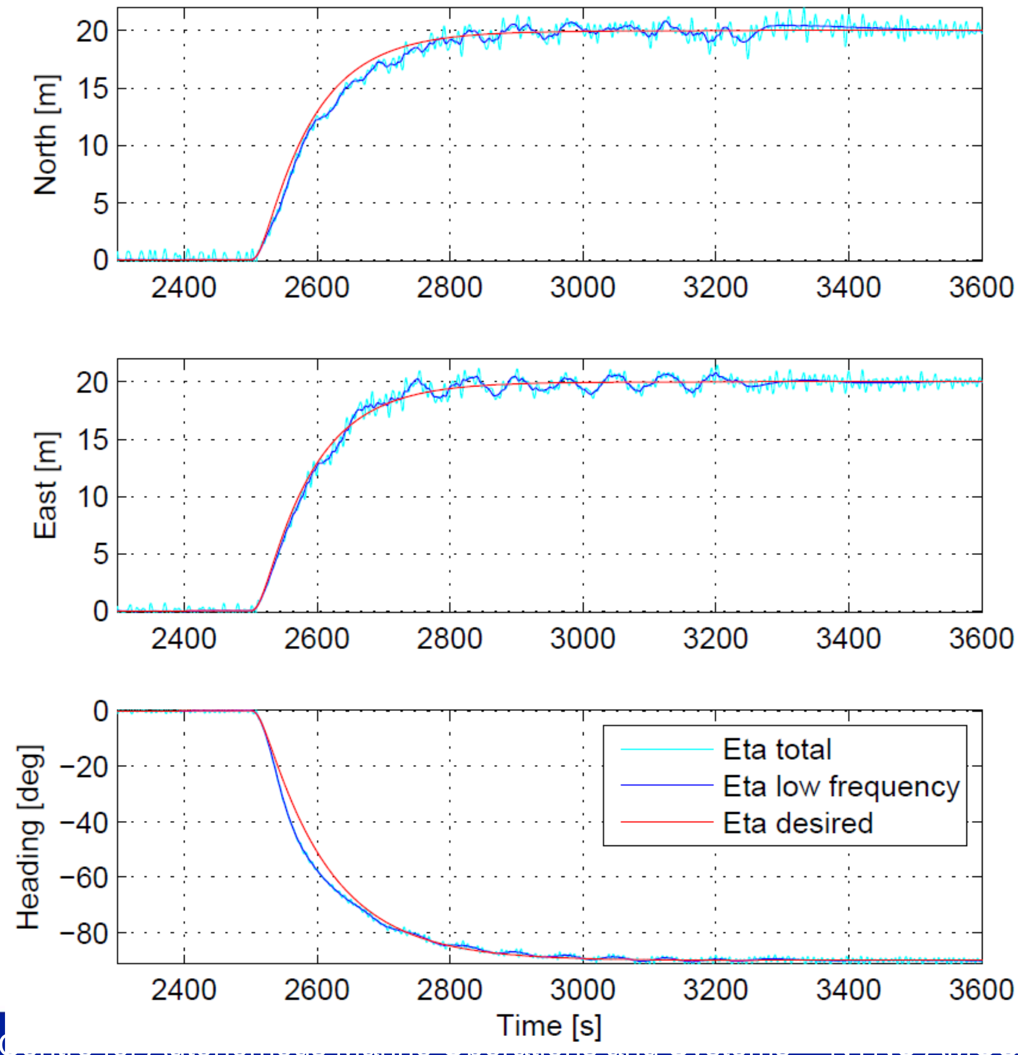
s=1 model-based and s=2 signal-based

Hybrid Signal-based and Model-based observer

(Astrid H. Brodtkorb)

Simulation study

Stationary Transient Stationary



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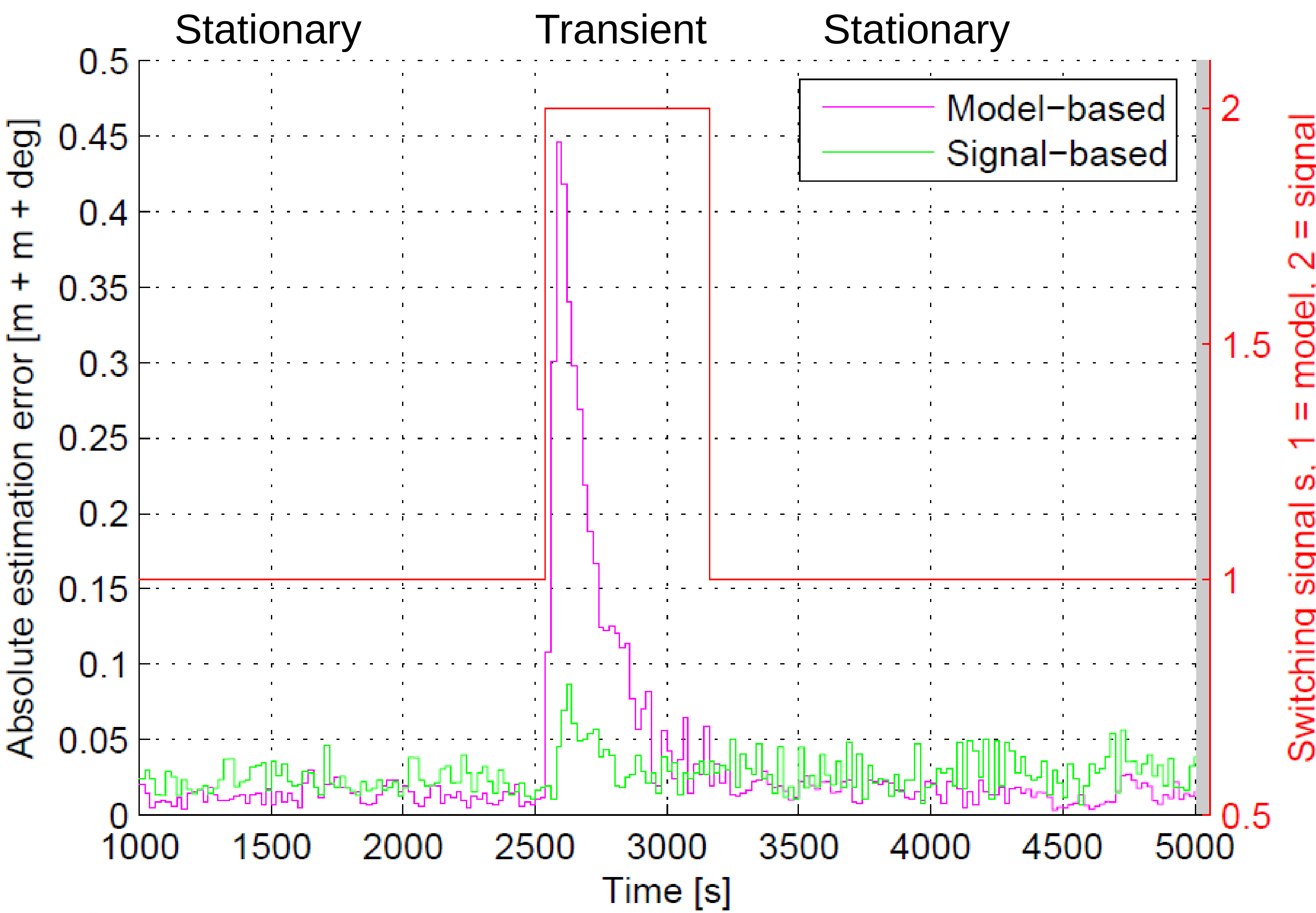
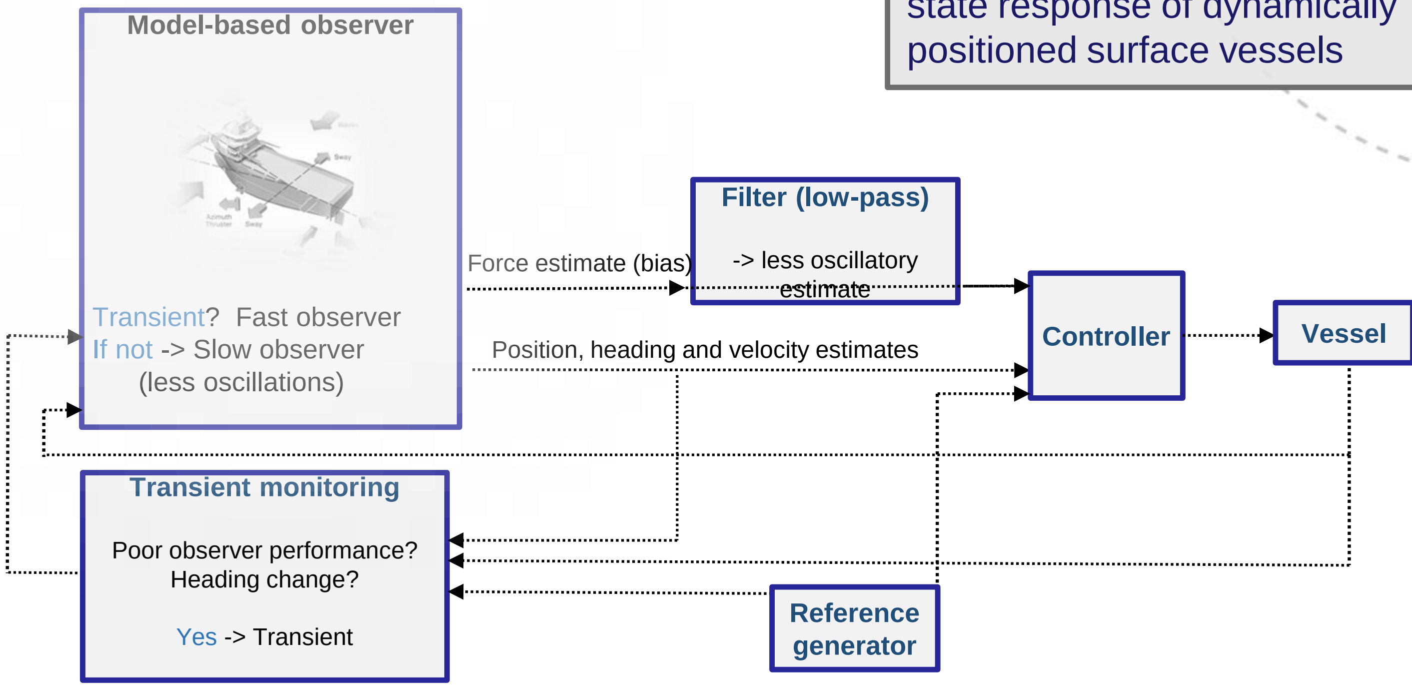


Model-based output feedback transient controller

(Svenn Are Værnø)

Overall goal

Good transient and steady state response of dynamically positioned surface vessels



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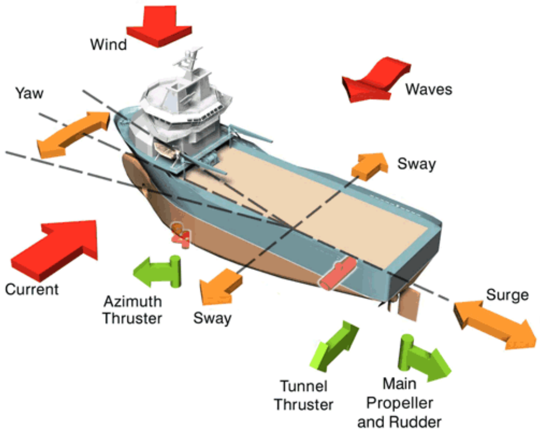
Model-based output feedback transient controller

(Svenn Are Værnø)



Courtesy: Kongsberg Maritime

Simulation study

- **Supply vessel**
  Lpp = 80 m
- **Environment**
  – Waves (Hs = 6m, ω_0 = .53 rad/s), current (0.5 m/s), wind (5 m/s)
- **Measurements**
  – Heading and position
- **Simulation case**
  – Setpoint change at 1000 seconds:
    - From $\eta = [0,0,0]^T$ to $\eta = [20m, 20m, -90^o]^T$
  – Environmental force (bias) change at 3000 seconds:
    - Direction of current changes 90 degrees

Comparison study

- «Nominal»: slow observer
- «Aggressive»: fast observer
- «Flexible»: with transient monitoring

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Model-based output feedback transient controller

(Svenn Are Værnø)

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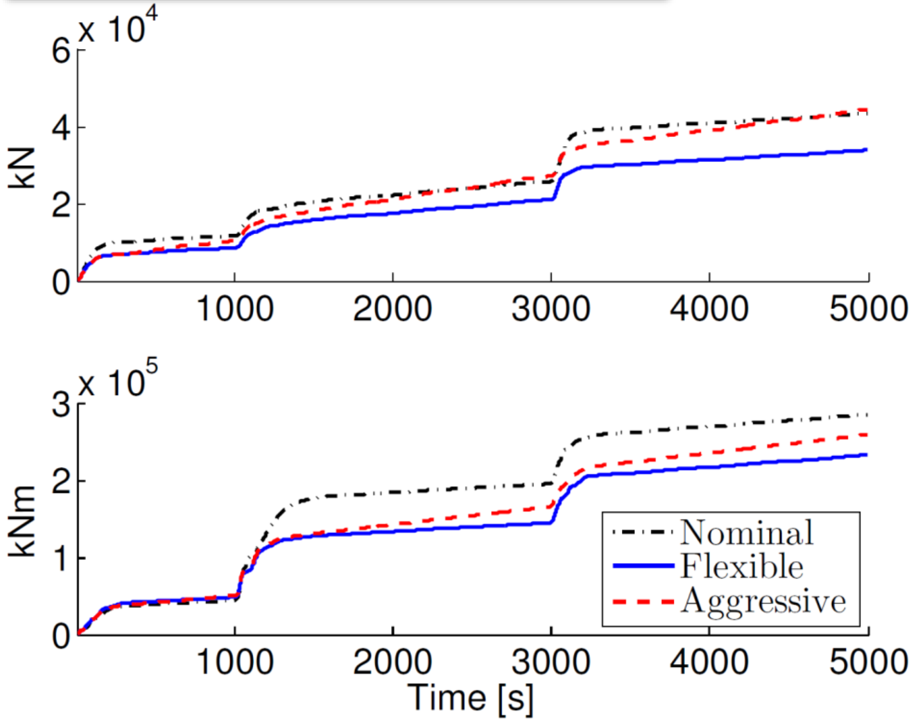

Fig: Cumulative environmental force (bias) estimation error: North+East (top), yaw (bottom)

Benefits:

- The proposed (flexible) design allows for
  - good estimation of the states in transients and steady state,
  - good environmental force compensation in transients,
  - good properties in steady state with less oscillations than the «aggressive» design
- Results in better positioning overall, especially if there are long periods of steady state between the transients

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Acceleration feedforward

(Øivind Kjerstad)

MRU 5+

Main concept

Investigate the potential of acceleration measurements for closed-loop stationkeeping of marine vessels.

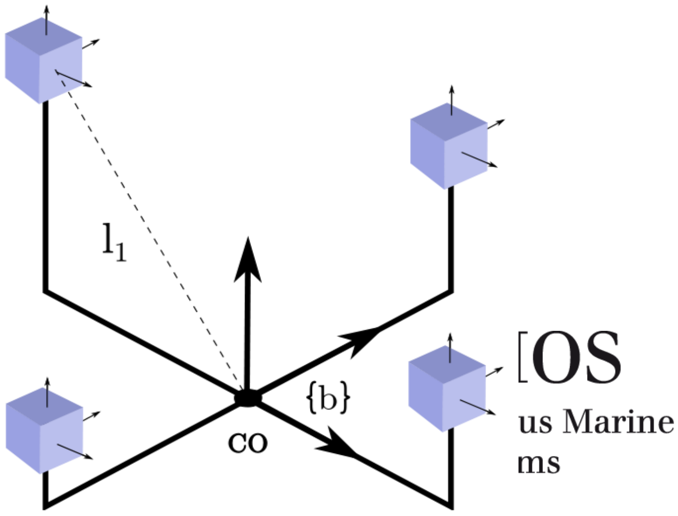
To use the system acceleration to calculate the acting external loads (and model errors) directly and filter these into the control law as a feedforward signal

Multi-IMU configuration

Apply a distibuted set of IMUs which collectively are transformed to CO, and by this also determining the angular accelerations

Complications:

- Gravity
- Bias
- Noise
- Linear sensor
- Sensor placement



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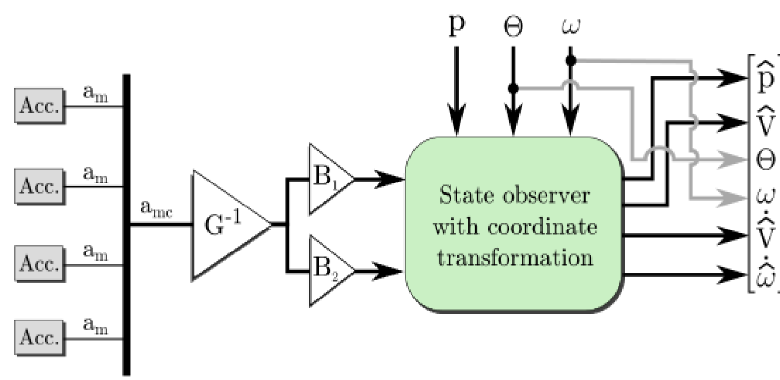

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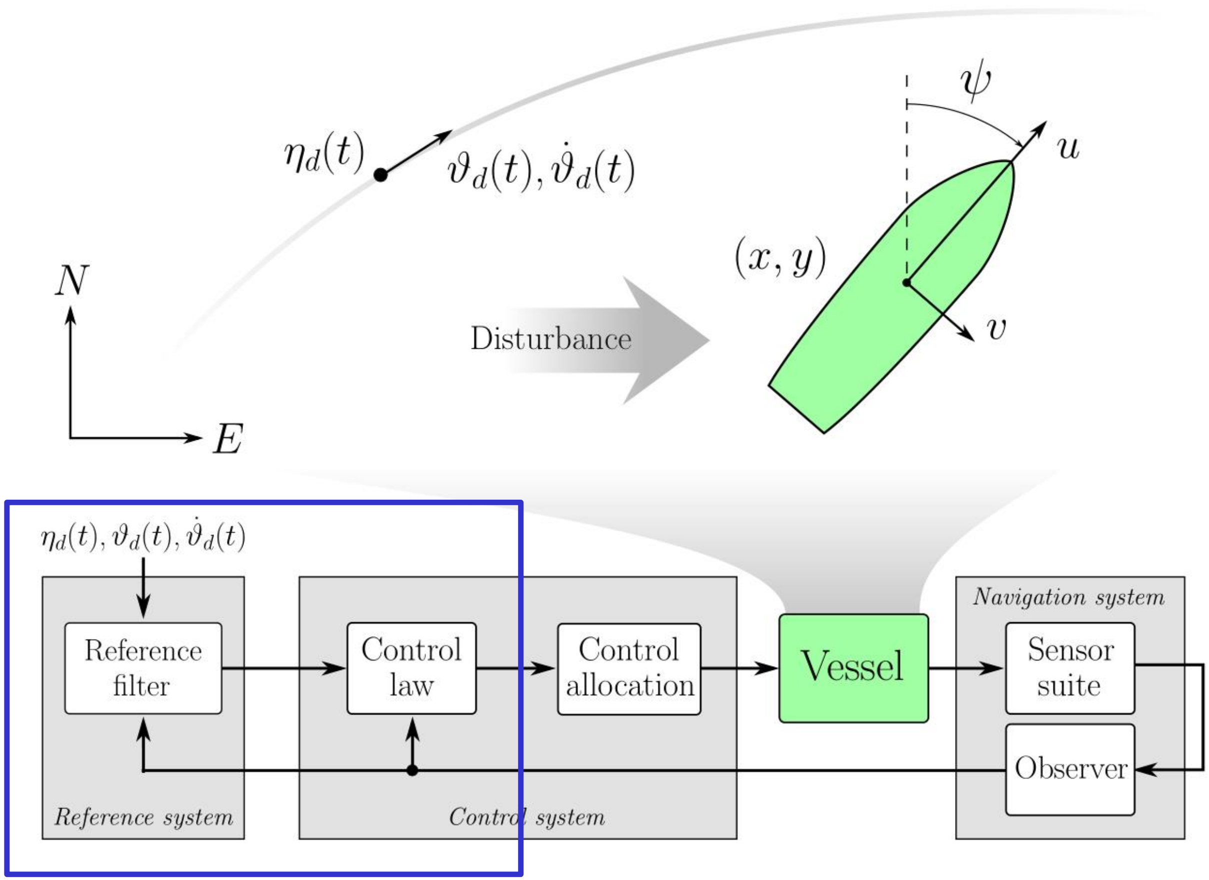
Operations and Systems

Pseudo-derivative feedback control
(Øivind Kjerstad)



Pseudo-derivative feedback control (PDF)

- Proposed by Richard M. Phelan in 1971
- Structurally similar to PID
- Difference from conventional PID is the lack of setpoint error in the proportional term
- Special case of weighted reference PID by Aström and Hägglund (1995)

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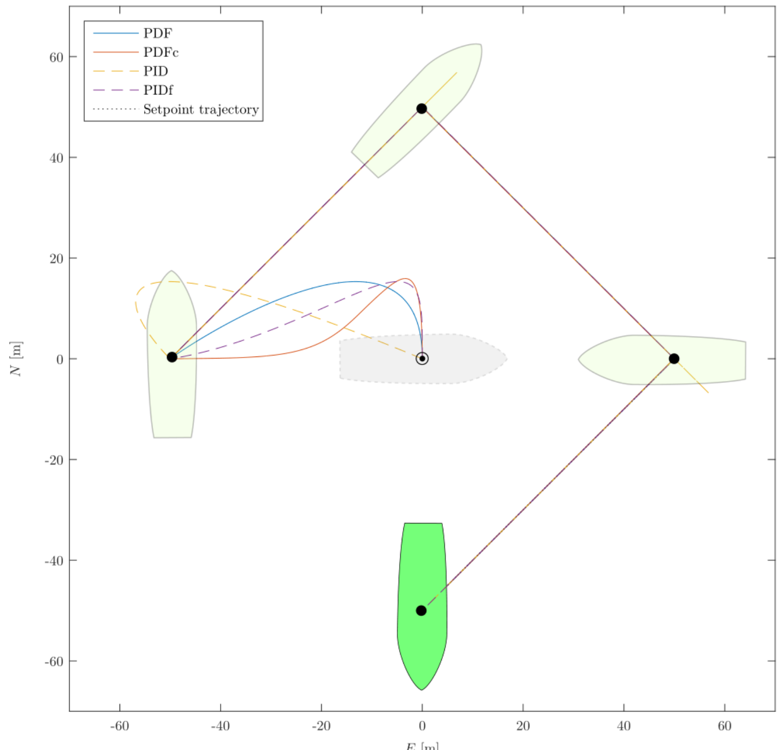
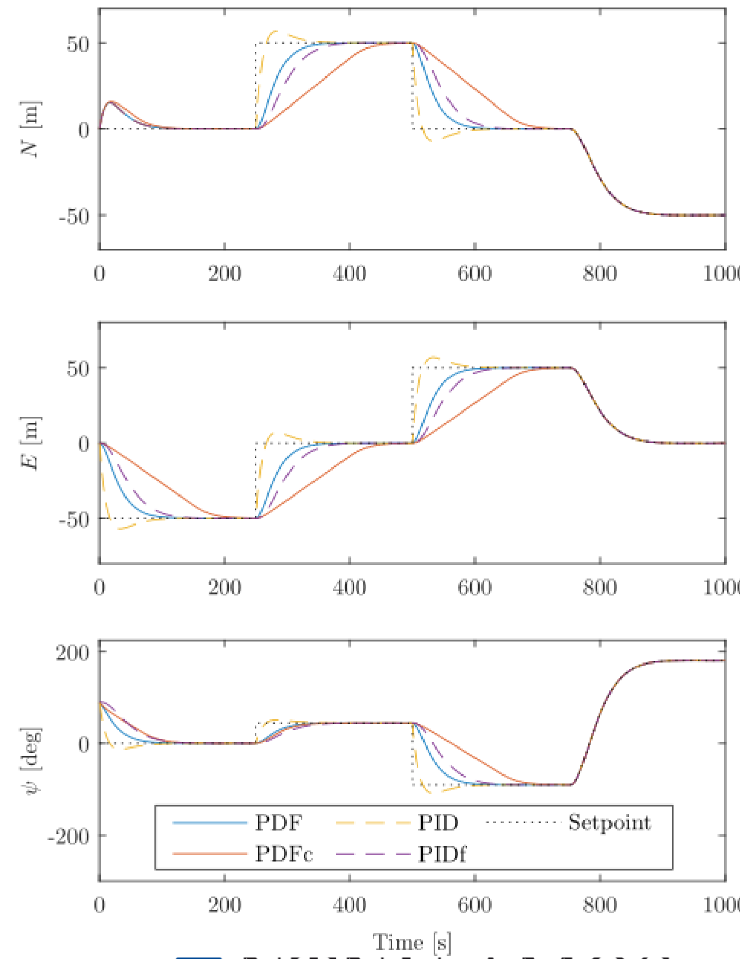
Pseudo-derivative feedback control

(Øivind Kjerstad)





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Summary

- Does not require a reference filter for setpoint steps or tracking
- Reduced number of tuning variables and implementation complexity (compared to PID)
- Easy to constrain the convergence velocity

Adaptive Control Schemes

(Mikkel Sørensen)

- Adaptive control is an established but interesting research topic
  - Account for variation in parameters
- Two experimental controllers are compared against a baseline controller using performance metrics
  - Adaptive backstepping (baseline controller)
  - Adaptive backstepping with nonlinear adaptation laws
  - Adaptive nonlinear cascaded feedback controller
- A standard way to evaluate the performance of the controllers has not been established

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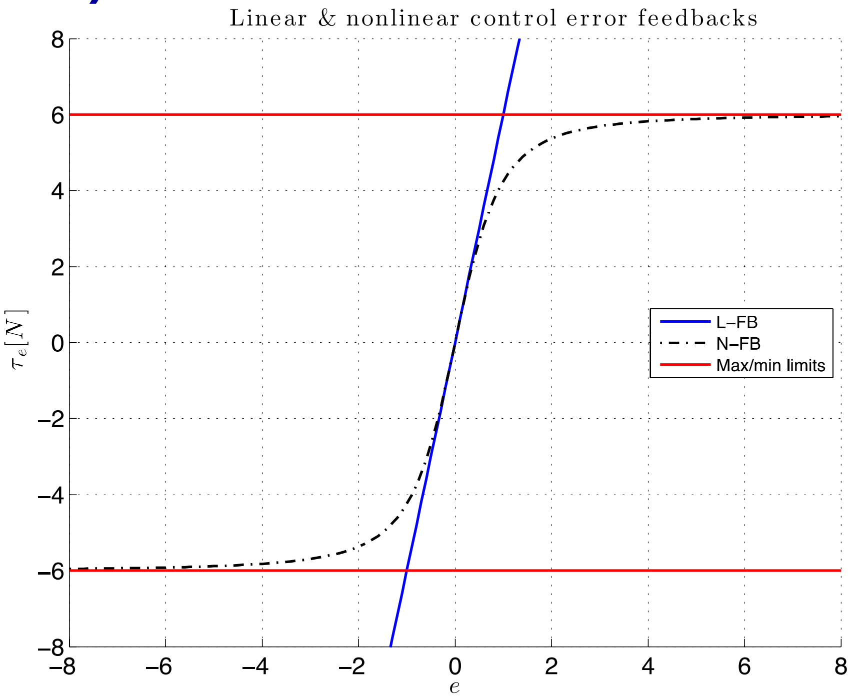
Adaptive Control Schemes

(Mikkel Sørensen)

- Adaptive backstepping (AB) with linear feedback (L-FB)
- AB with nonlinear update laws
  - Introduce nonlinear feedback (N-FB) into the update laws
- Adaptive nonlinear cascaded feedback control
  - Remove internal feedback
  - Prove ISS
  - Introduce N-FB into the pose and velocity feedback terms



$$\text{L-FB} = Ke$$

$$\text{N-FB} = K\frac{e}{\sqrt{e^2 + \Delta^2}}$$

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What's Next?

- The first cruise gave good results on a lot of the controllers
  - observers were more difficult
  - great collaboration with KM
  - bugs were fixed
  - the system did not crash ☺
  - good preparation for the next cruise
- Next cruise: Week 46

Planned journal publications:

- **"Hybrid observer for Improved Transient Performance of a Marine Vessel in Dynamic Positioning",** Astrid H. Brodtkorb, Svenn Are Værnø, Andrew R. Teel, Asgeir J. Sørensen, Roger Skjetne, Vincenzo Calabrò
- **"Experimental Results of an Output Feedback Controller with Improved Transient Response of Marine Vessels in DP**", Svenn Are Værnø, Astrid H. Brodtkorb, Roger Skjetne, Asgeir J. Sørensen, Vincenzo Calabrò

Planned conference publications:

- **"The NTNU AMOS DP Research Cruise 2016 with R/V Gunnerus for full-scale testing of experimental dynamic positioning control system algorithms",** Roger Skjetne, Svenn Are Tutturen Værnø, Astrid H. Brodtkorb, Mikkel Eske Nørgaard Sørensen, Øivind Kåre Kjerstad, Vincenzo Calabrò, Morten Breivik, Asgeir Johan Sørensen

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Thanks For Your Attention