Mitigating Excessive Pitch and Roll Motions for Semi-Submersibles

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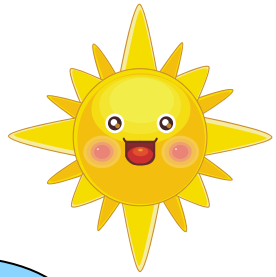
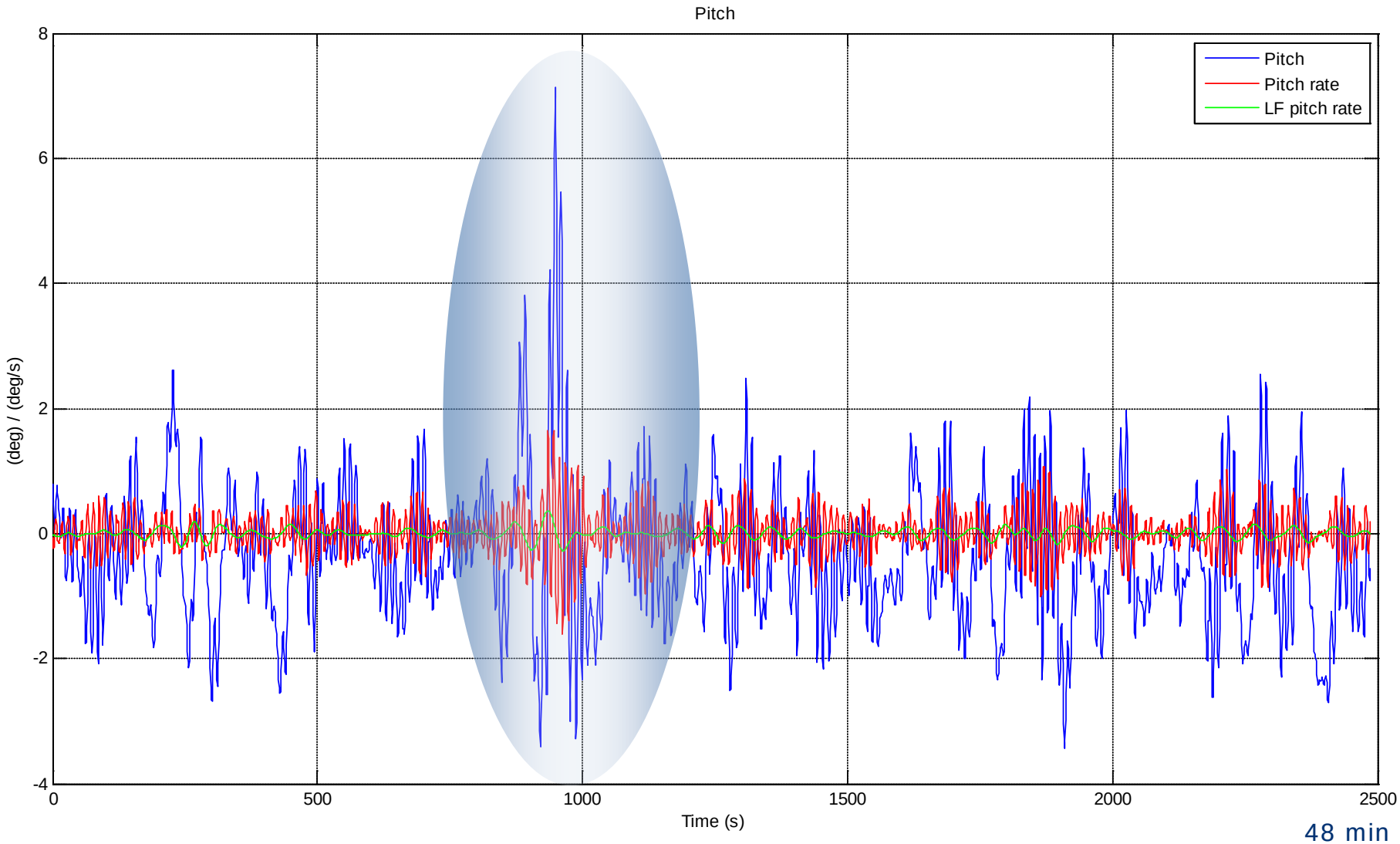
Background

- Observed large pitch and roll motions on (some) new 6. generation drilling rigs
- Natural pitch and roll periods significantly longer than for previous generation semis
- Resonance between hull and mooring in shallow waters
- Thrusters may amplify natural pitching and rolling



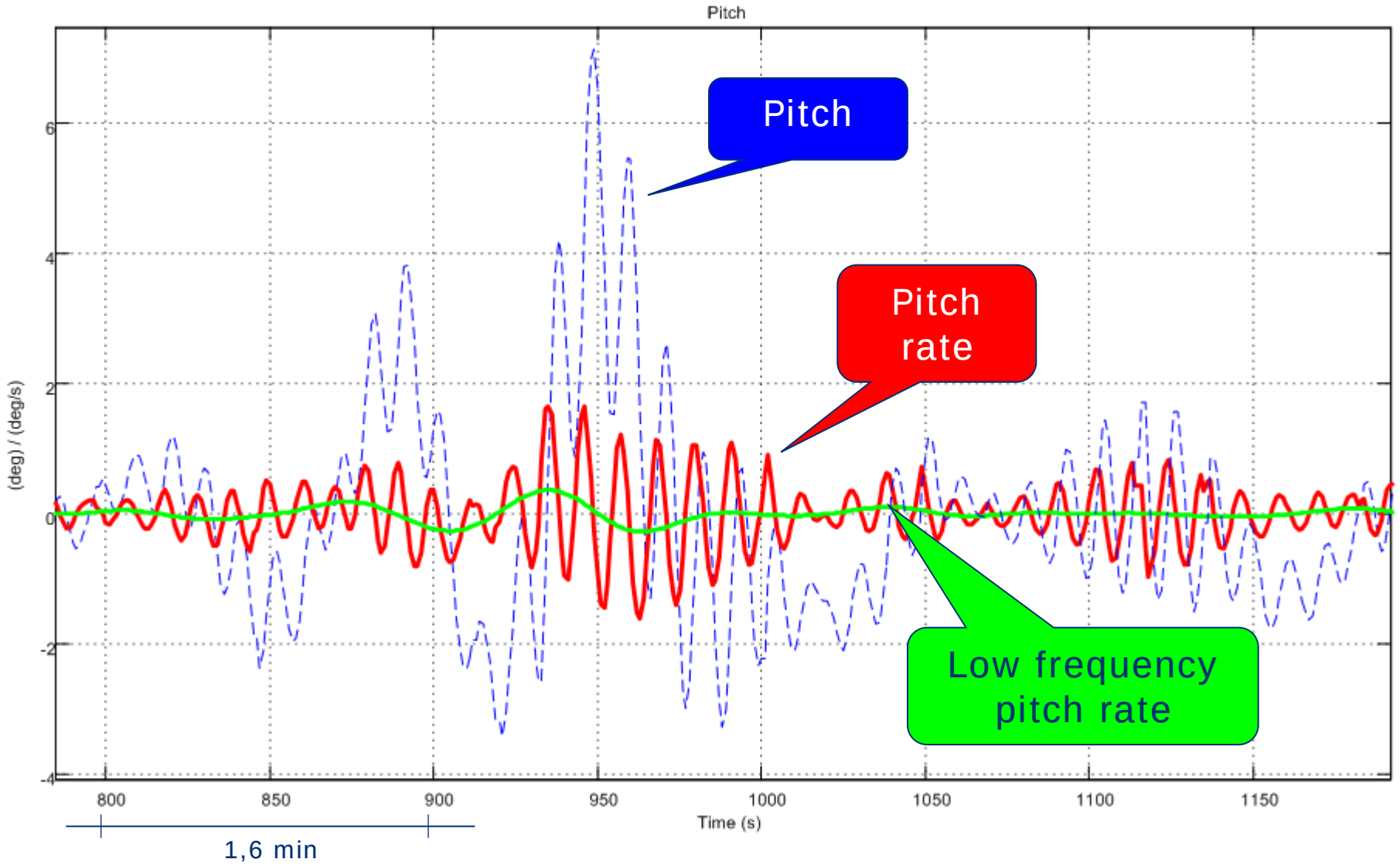
- Can problems be mitigated by using the thrusters?
- Is pitch and roll rate feedback control feasible?

Recorded pitch motion



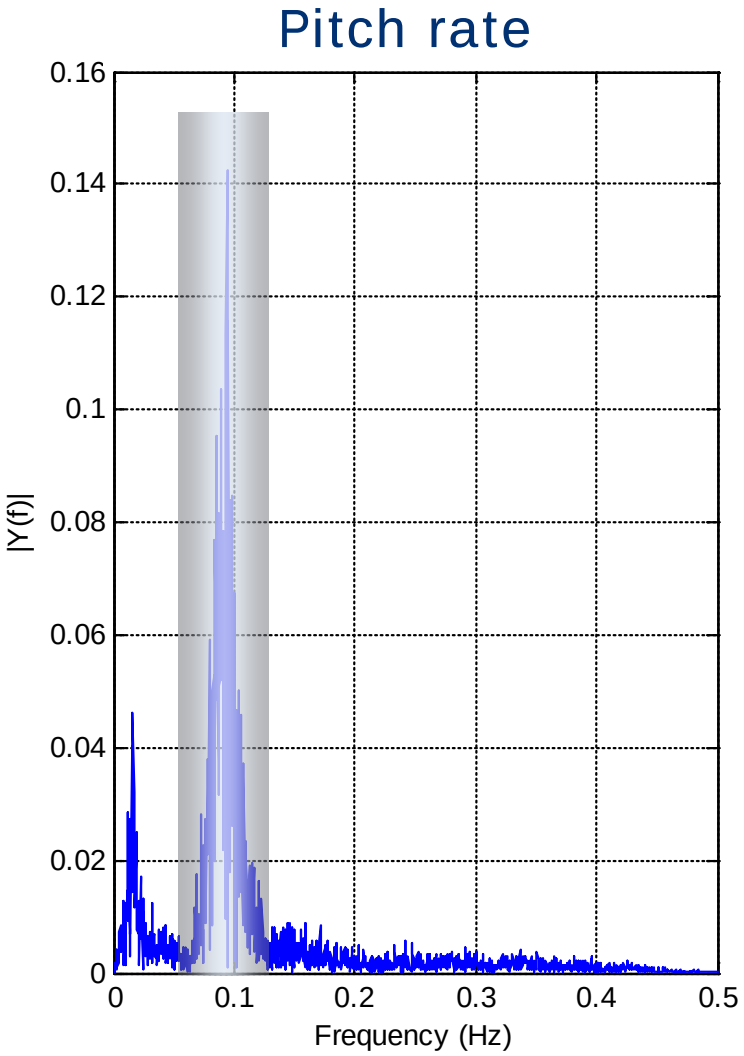
48 min

Recorded pitch motion

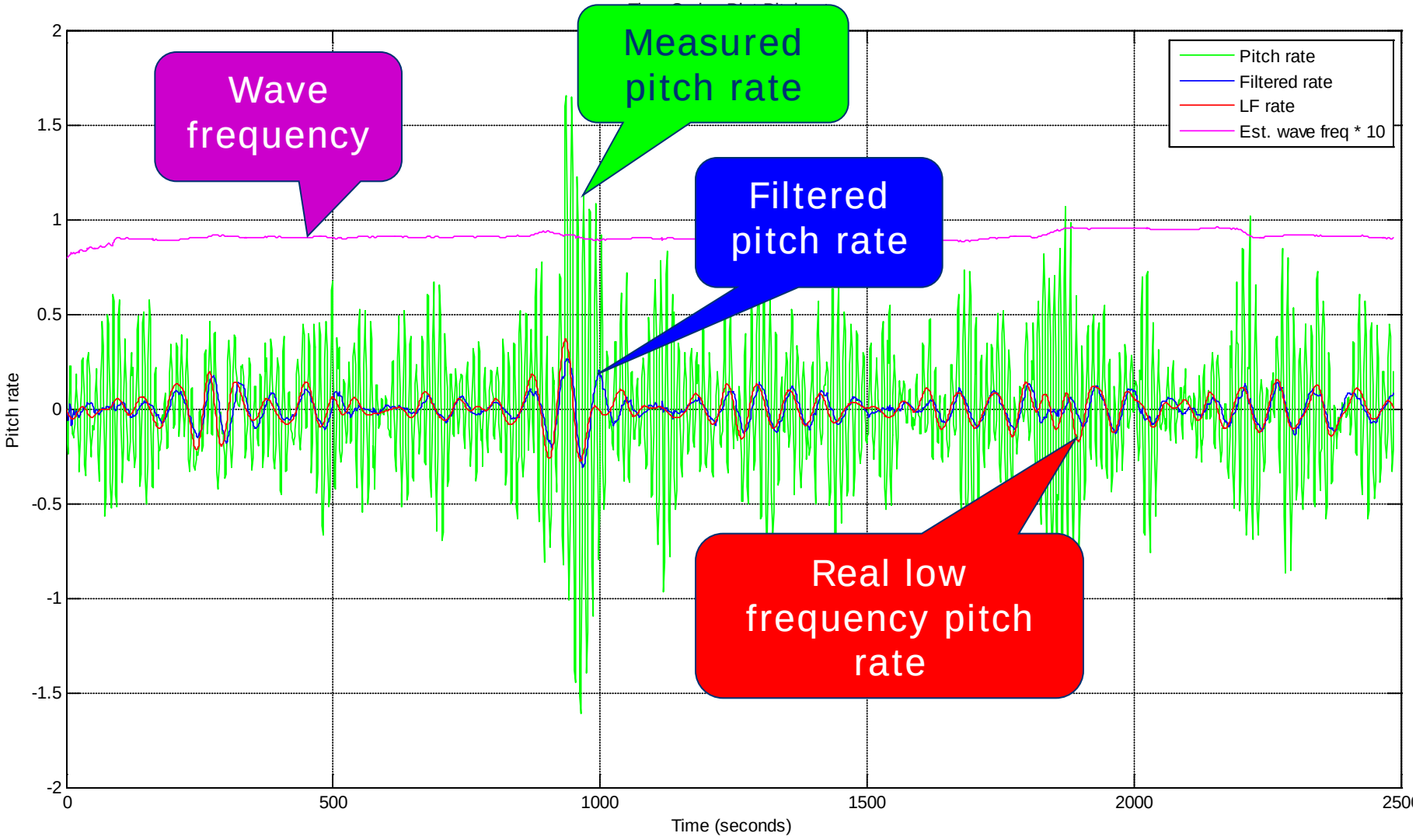


Pitch rate control

- Observations:
  - Wave period ≈ 10 sec
  - Natural oscillation period ≈ 50 sec
  - Wave motion dominant
- Pitch rate signal can not be used for control directly
- Need to filter out wave frequency components
- Dual oscillator filter
  - Natural oscillation period
  - Wave period
  - Adaptive to changing wave characteristics



Adaptive wave filtering



Vessel dynamics

- Pitch – surge motions are dynamically coupled

$$m_{11}\dot{u} + m_{15}\dot{q} + d_{11}u = \tau_x$$

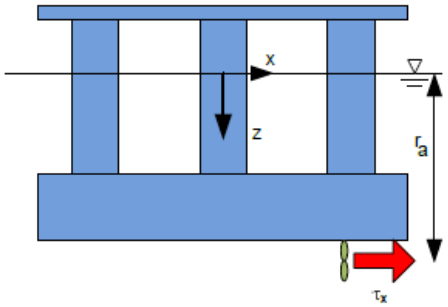
$$m_{51}\dot{u} + m_{55}\dot{q} + d_{55}q + g_{55}\theta = \tau_x r_a$$

where

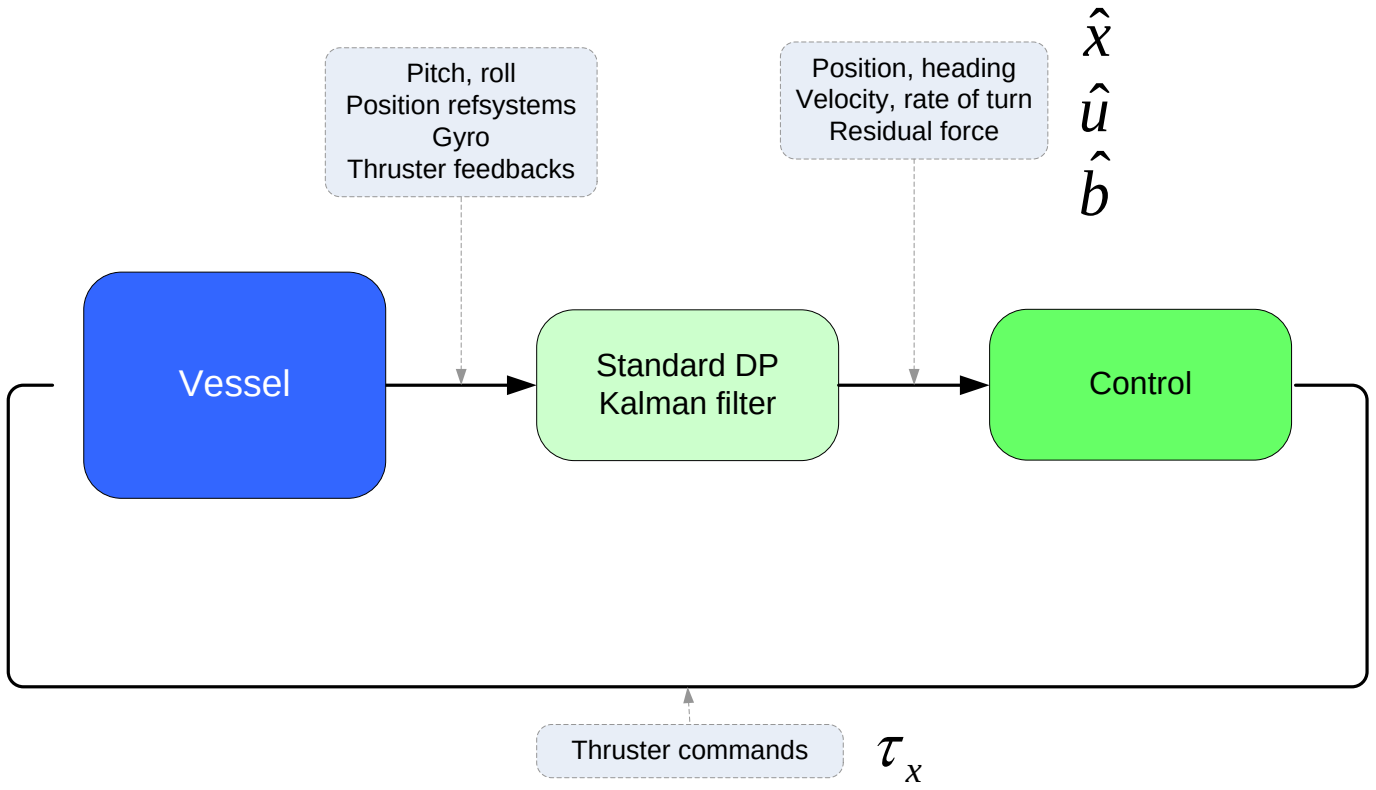
u	surge velocity
q	pitch rate
θ	pitch angle
m	inertia parameters
d	damping parameters
τ	Thrust

Mechanical coupling

Hydro dynamical coupling



Control

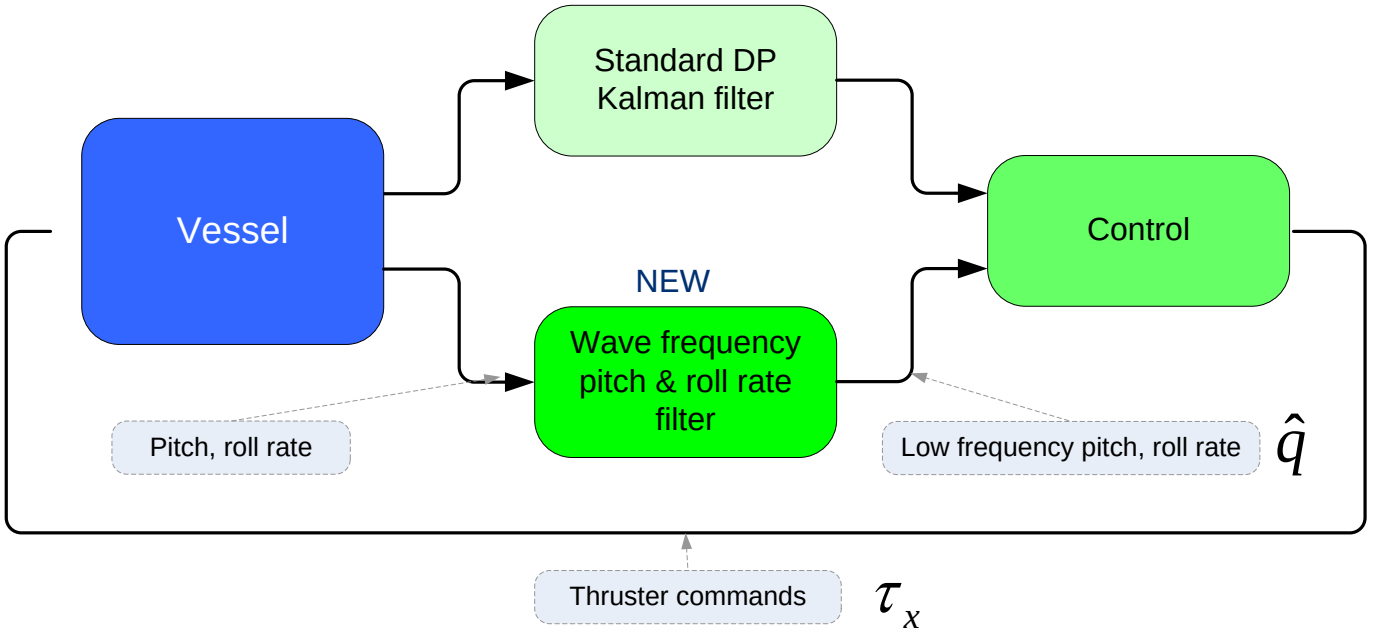


Thrust command

$$\tau_x = -g_{21}\hat{x} - g_{22}\hat{u} + \hat{b}$$

$\hat{x}$	Low frequency surge position
$\hat{u}$	Low frequency surge velocity
$\hat{b}$	Estimated residual forces

Control



Thrust command

$$\tau_x = -g_{21}\hat{x} - g_{22}\hat{u} + \hat{b} - g_{51}\hat{q}$$

$\hat{x}$	Low frequency surge position
$\hat{u}$	Low frequency surge velocity
$\hat{b}$	Estimated residual forces
$\hat{q}$	Low frequency pitch rate

Simulation example

- Vessel and DP system is simulated

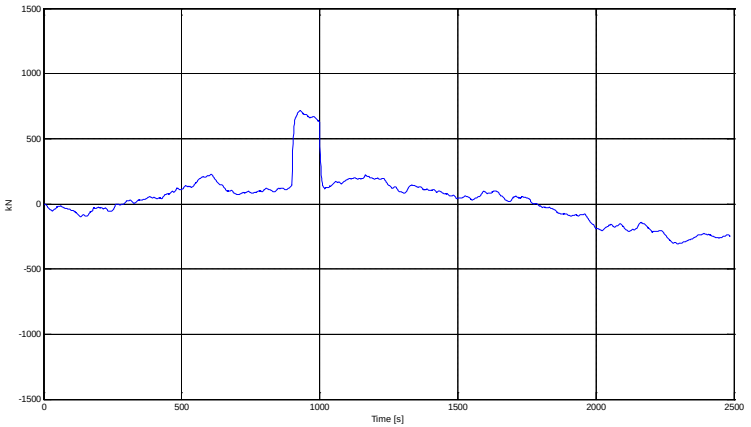
$$m_{11}\dot{u} + m_{15}\dot{q} + d_{11}u = \tau_x + \delta$$
$$m_{51}\dot{u} + m_{55}\dot{q} + d_{55}q + g_{55}\theta = (\tau_x + \delta)r_a$$

$$\tau_x = -g_{21}\hat{x} - g_{22}\hat{u} + \hat{b} - g_{55}\hat{q}$$

$$\begin{bmatrix} \hat{x} \\ \hat{u} \\ \hat{b} \\ \hat{q} \end{bmatrix} = \begin{bmatrix} f(\hat{x},\hat{u},\hat{b},\tau_x) & 0 \\ 0 & g(\hat{q}) \end{bmatrix} \begin{bmatrix} x^{measured} \\ q^{measured} \end{bmatrix}$$

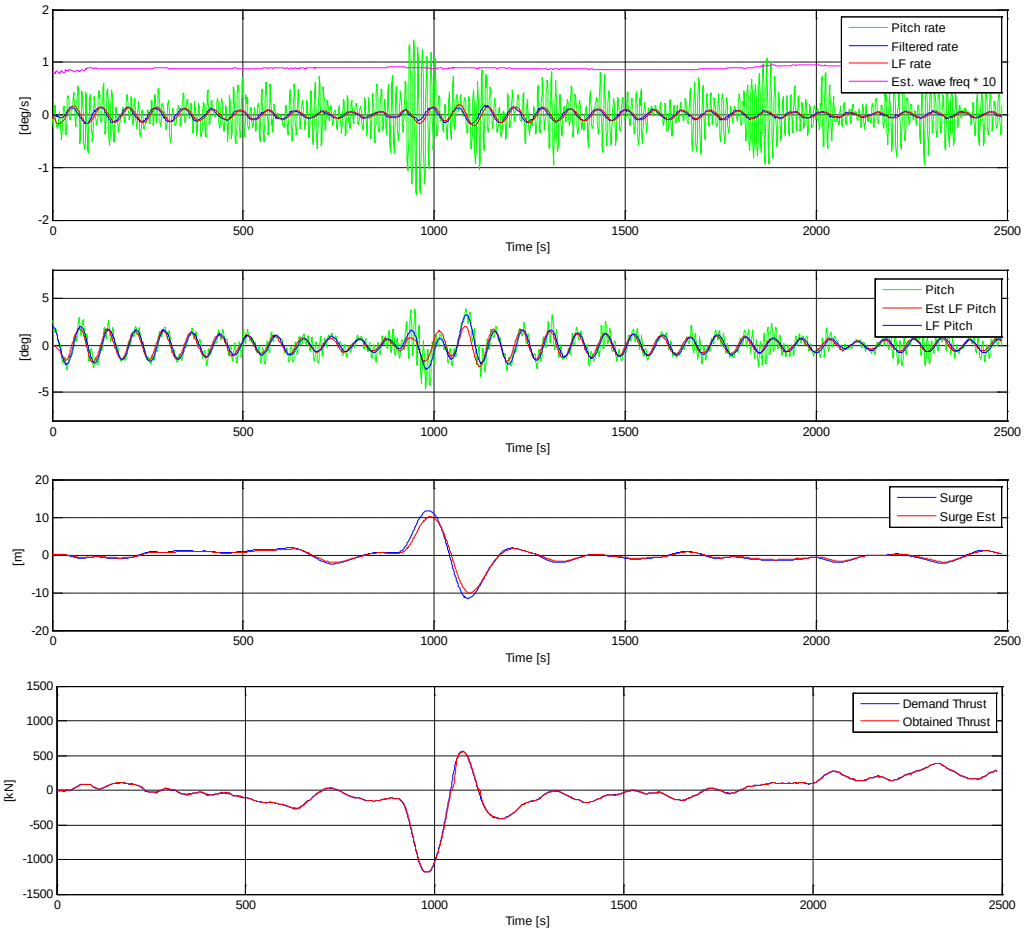
where δ is a disturbance

- slowly varying random value
- pulse 50 tonnes for 100 sec



Normal DP control

- Almost persistent pitching



Pitch rate

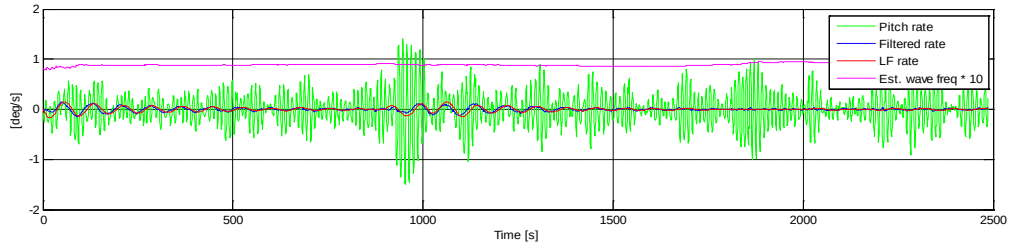
Pitch

Surge

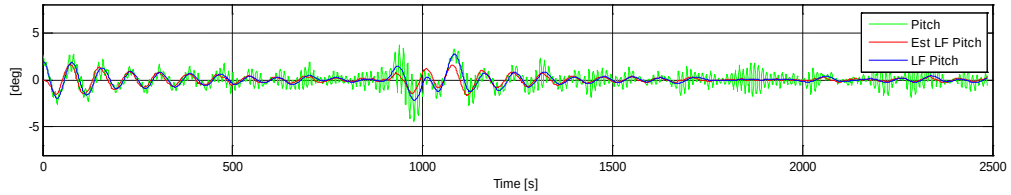
Thrust

DP with pitch rate feedback

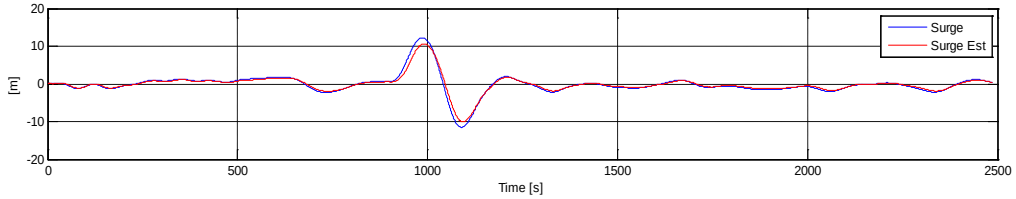
- *Well damped pitching*



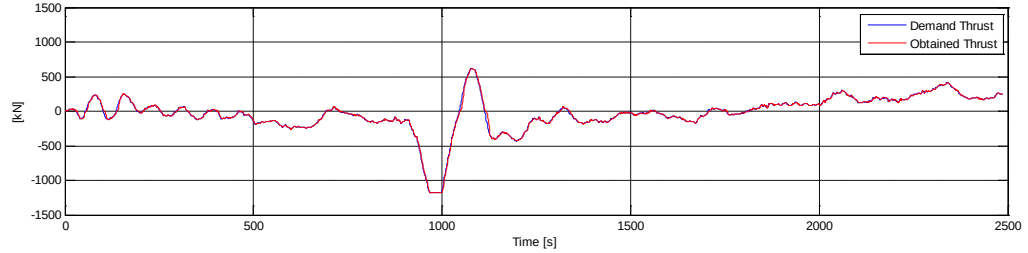
Pitch rate



Pitch



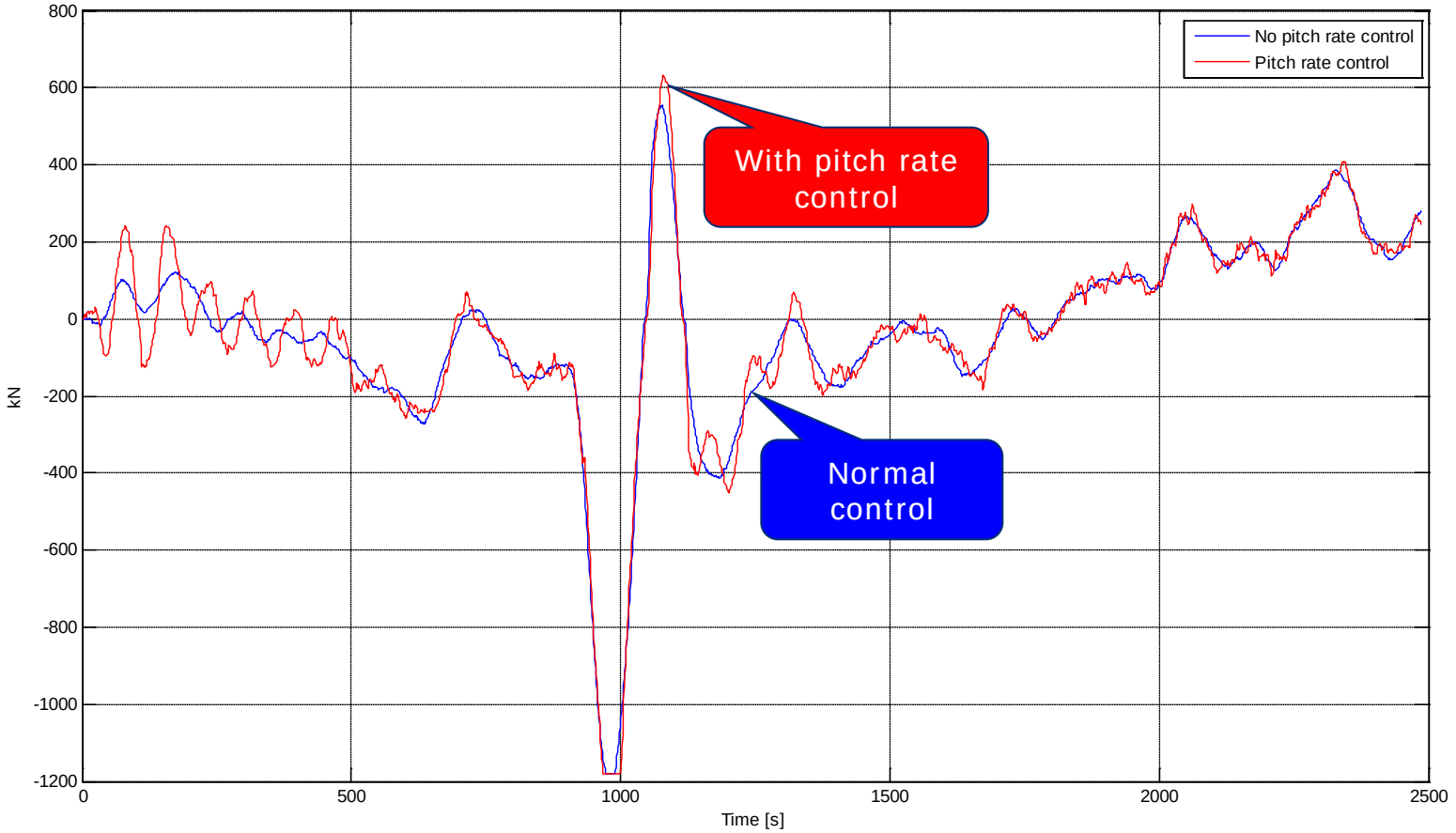
Surge



Thrust

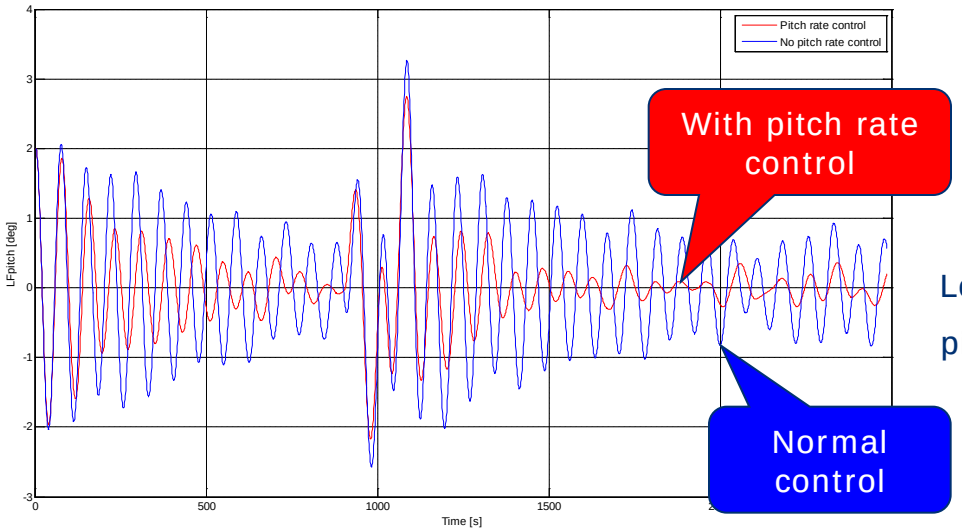
Thruster command details

- Pitch rate control does not require significant additional thrust



Conclusions

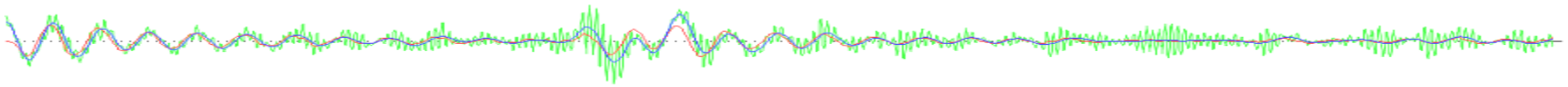
- The overall pitching and rolling can be reduced
- A significant damping of the low frequency pitch and roll motions may be expected
- For sudden external excitation the pitch rate control can not significantly improve the immediate transient pitching but will dampen the effect over time
- No improvements can be expected for the wave frequency components



Low frequency pitch

Thank you for your attention

Questions?



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