Return to Session Directory

DYNAMIC POSITIONING CONFERENCE
October 12-13, 2010

DESIGN

Mitigating Excessive Pitch and Roll Motions on Semi-Submersibles

By Nils Albert Jenssen

Kongsberg Maritime AS
Kongsberg
Norway

Introduction

The work is carried out as a consequence of observed large pitch and roll motions on some new 6th generation drilling rigs. The big pitch/roll motions are a combination of wave frequency motions and more lower frequency motions most likely caused by resonance between hull and mooring / DP system.
Natural pitch and roll periods of the vessels are significantly lower than the dominant wave period and also lower than what has earlier been observed with previous generation semis due to bigger mass without correspondingly increased hydrostatic restoring.

The goal of the study has been to derive a new control feature in the K-Pos DP system to mitigate the pitch and roll problems. For simplicity only pitch and surge motion is considered in this paper.

Data Analysis

Several recordings have been done showing extreme pitch and roll motions. Pitch and roll motions may be of equal character, or one of the motion components may be most important; this depends on the actual weather condition.
In this case study the pitch motion is dominating. Recorded pitch data are shown in the figure below.

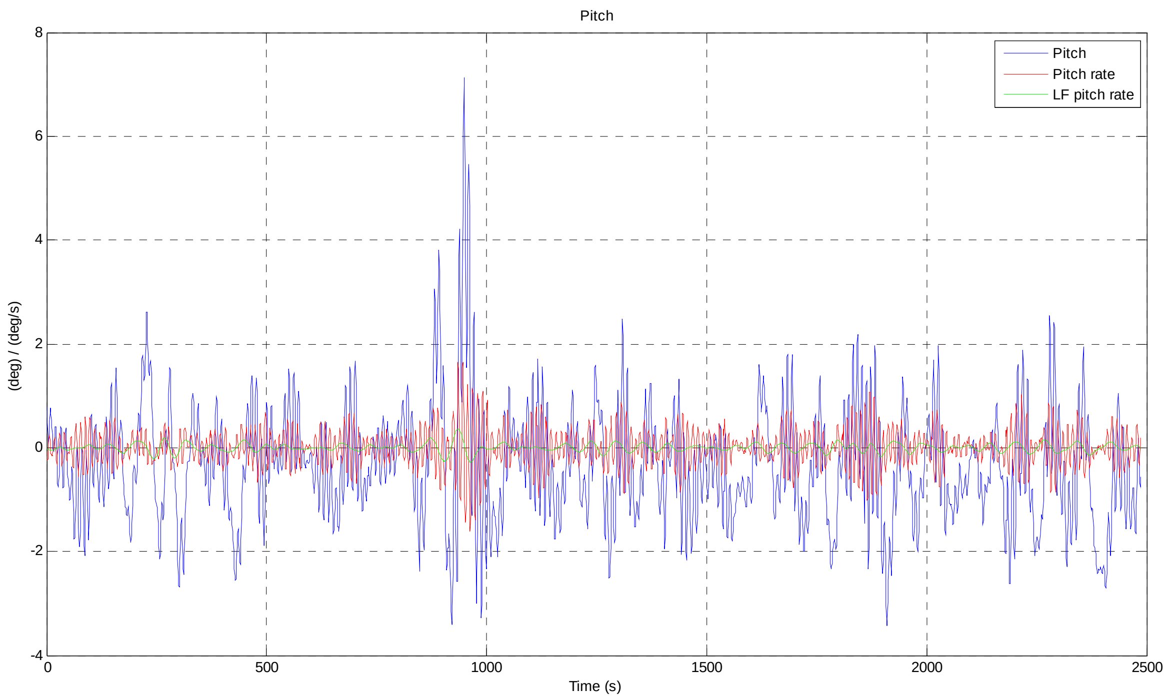

Figure 1 Recorded pitch

Unfortunately we have no recordings of pitch or roll rates. But since the signal are very smooth rate calculations can be done with good accuracy numerically.
The pitch rate (red) is found by numeric differentiation of the pitch signal and the low frequency pitch rate (green) is found by ideal-filtering the pitch rate from 0 to 0.03 Hz. Both the filtering and differentiation maintains phase for the signals (no lead/lag is introduced). Unfortunately this can not be achieved in real time.

A detailed snapshot at 1000 sec is shown below.

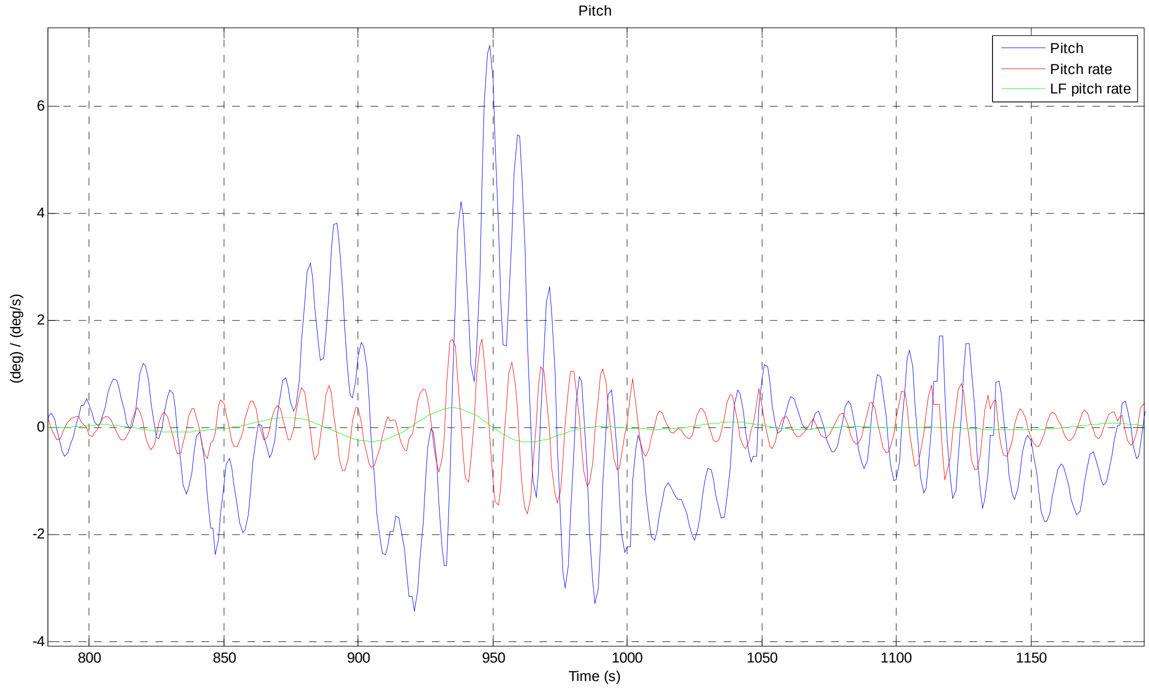

Figure 2 Recorded pitch (details)

Looking at the pitch rate we clearly observe that the wave frequency component of the pitch rate is dominating. The signal to noise ratio is about 0.25 (-12dB) rms. The signal is the green curve and the noise is the red curve minus the green curve.

The recorded time series show to distinct frequency regions:

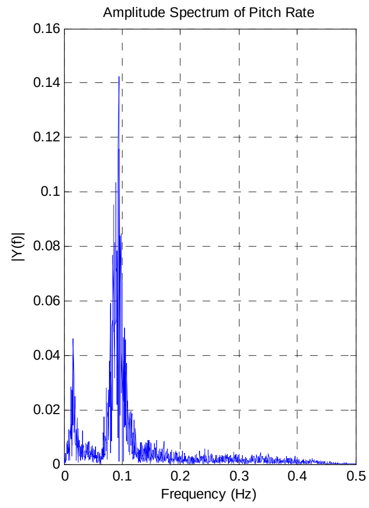

Figure 3 Pitch rate spectrum

We see very clearly that it is the wave frequency region which dominates.

To mitigate pitching a thruster feedback control from pitch rate could be applied. Using pitch/roll rate measurements directly for control is not feasible since thrusters are not quick enough to counteract wave motions, and doing so would also represent a major wear and tear on the thrusters. Wave motion filtering is hence necessary.

Wave Filter

A dual oscillator based filter is developed with one oscillator modeling the natural pitch/roll period of the semi-sub and one wave frequency oscillator. The wave frequency oscillator has to be self adaptive to the dominant wave frequency. The other one must be calculated on-line (parameter scheduled) according to the vessels moment of inertia and meta-centric height (up-righting moment).

Results of applying the filter to the signal in Figure 2 are shown below.

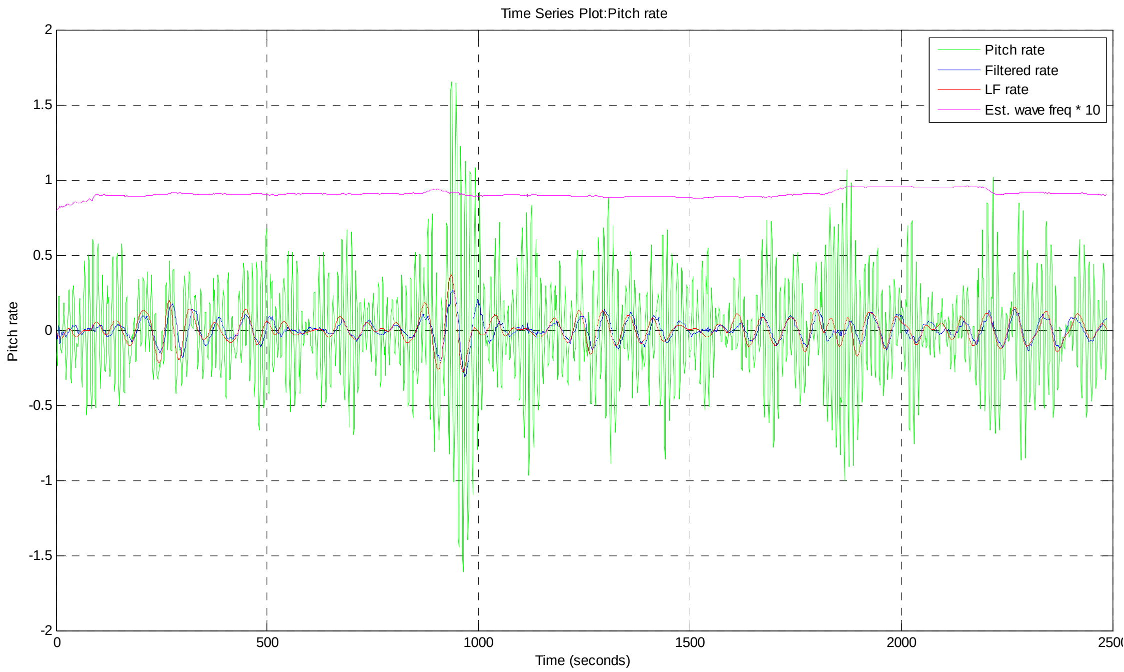

Figure 4 Wave filter

Note the following color scheme:

Red	is the true low frequency value corresponding to the natural oscillation frequency of the vessel, denoted LF rate
Blue	is the estimated value of the same derived from the wave notch filtering
Green	is the measured pitch rate
Magenta	is estimated dominant wave frequency (units of 10 Hz)

The filter is self adapting to the experienced wave frequency. In general the filter reveals a small lag, but this should not cause feedback control problems.

Another question is how robust the filter is regarding changing rig parameters. In the figure above vessel natural period is set to 0.015 Hz (67 seconds) according to Figure 3. Reducing the assumed natural pitch period to 50 seconds results in:

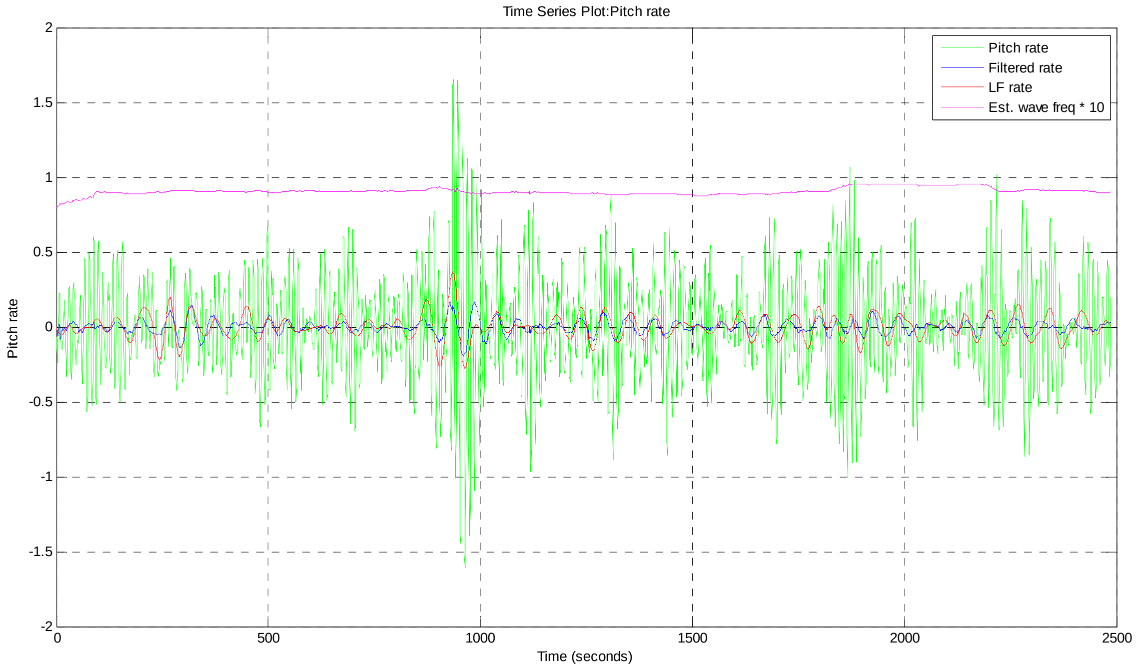

Figure 5 Wave filter 50 sec

Increasing the assumed natural pitch period to 90 sec:

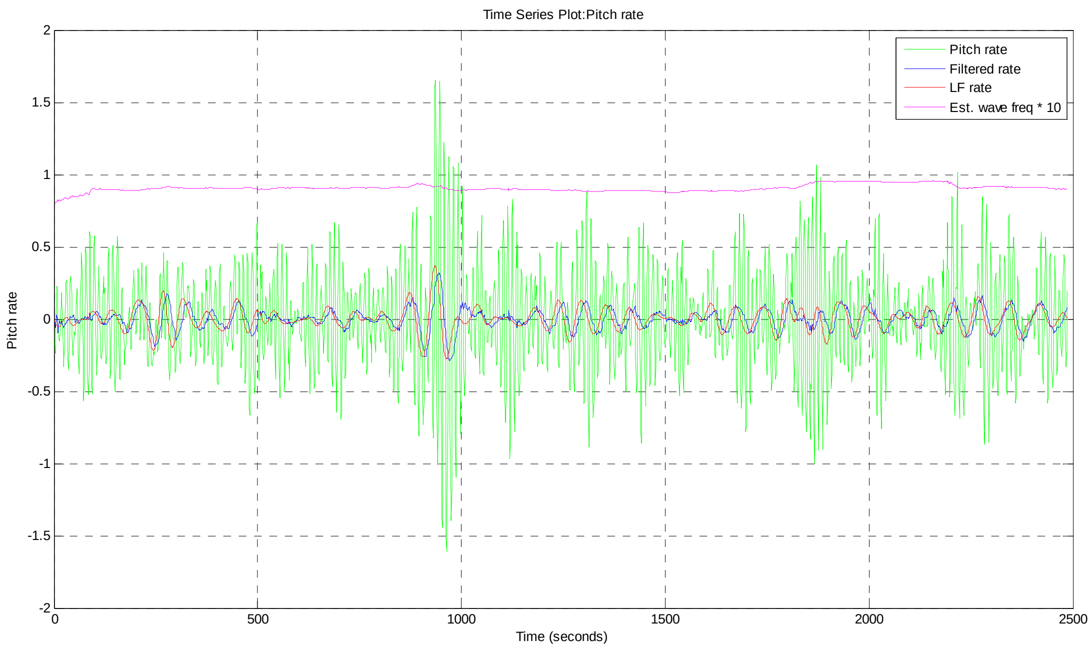

Figure 6 Wave filter 90 sec

Comparing Figure 4, Figure 5 and Figure 6 we observe that the estimated (filtered) pitch rate in Figure 5 has a small lead compared to the real low frequency pitch rate where as Figure 6 shows a small lag. For control stability lag is a problem, but the magnitude shown should not cause control problems.

The adapting to wave frequency is robust regarding start-up value.

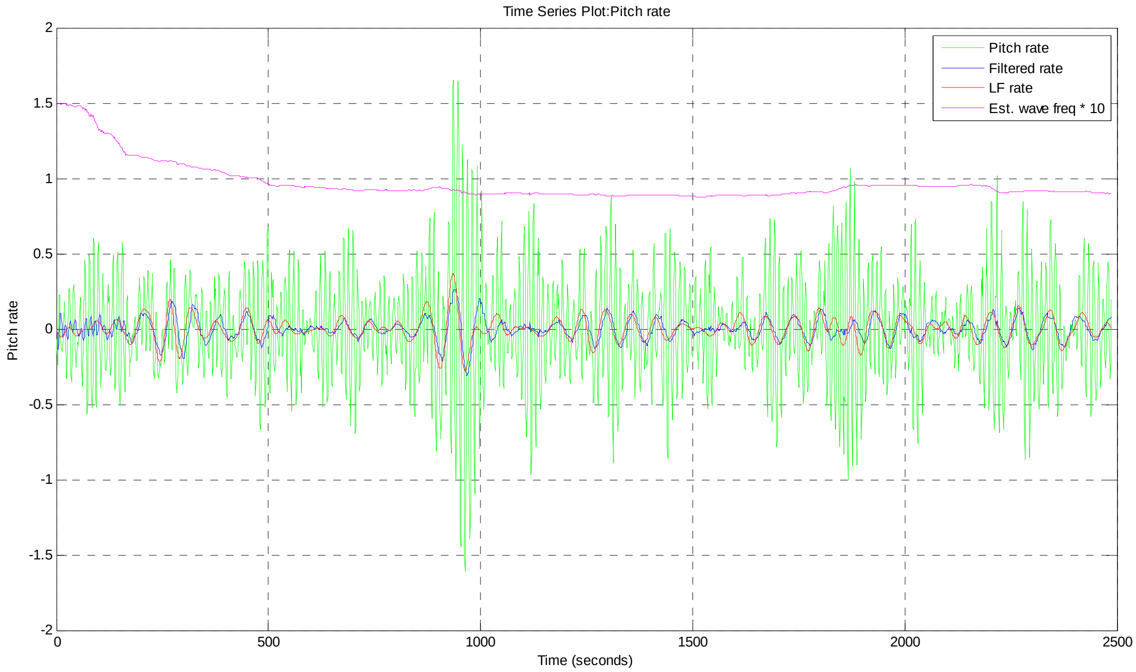

Figure 7 Wave filter – wave start-up 0.15 Hz

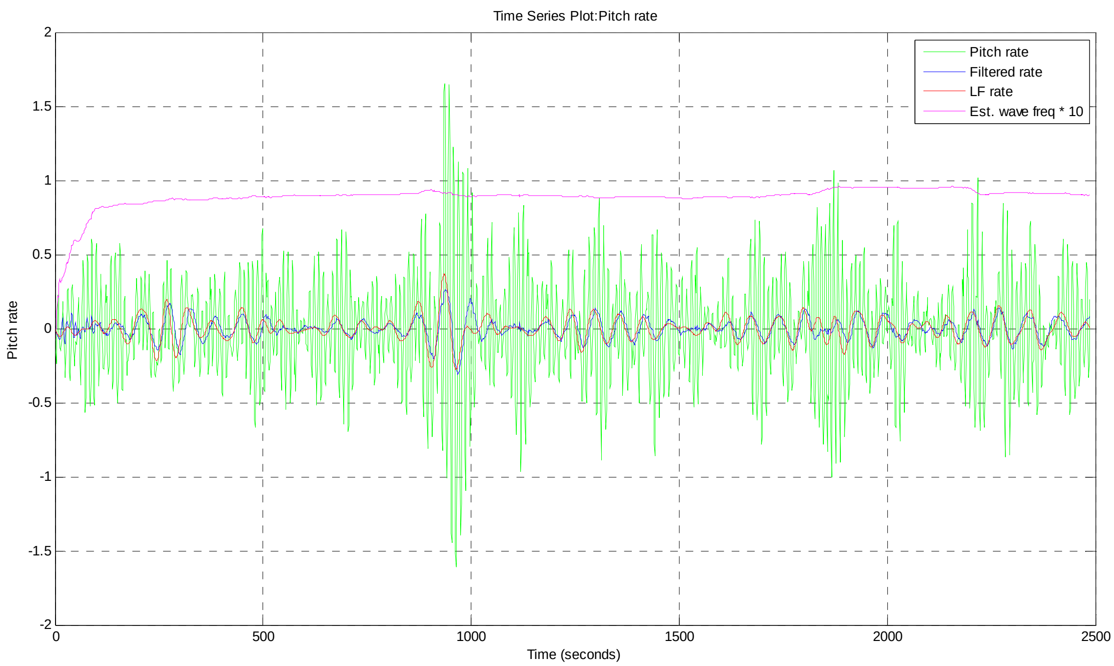

Figure 8 Wave filter – wave start-up 0.0 Hz

A mathematical model of the low and high frequency pitch/roll motion is used in an adaptive Kalman filter with pitch/roll rate as measurement.

Closed Loop Control

Mathematical simulation model

Combined low frequency pitch and surge motions may be described by the following set of equations:

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

where

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

In addition wave frequency pitch motions are superimposed.

The same couplings are also present for the sway and roll degrees of freedom.

A normal DP control for station keeping is used with the following control law:

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

where

- $\hat{x}$ estimated surge position
- $\hat{u}$ estimated surge velocity
- $\hat{b}$ estimated residual forces (caused by current and wave drift as well as other un modeled phenomena)
- g gain parameters

In addition rise and fall times for thruster rpm are taken into account.

The pitch of the simulated rig is started at non equilibrium in order to study the damping of the rig. The rig is also exposed to en external disturbance with a significant peek to study disturbance mitigation.

The disturbance is shown in the figure below. The same disturbance is applied to all simulations.

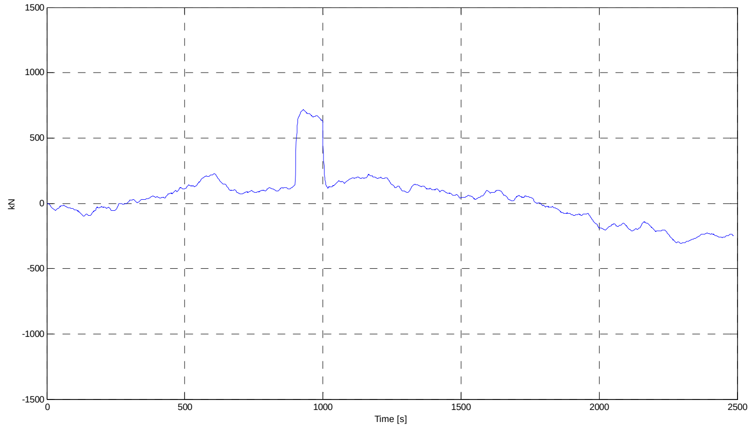

Figure 9 Disturbance

Ordinary DP control

No pitch rate control is applied.

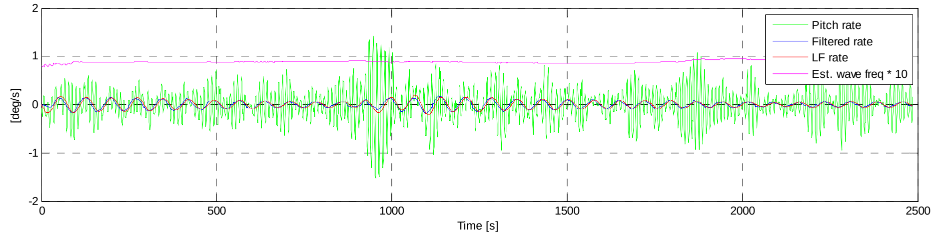

Figure 10 Pitch rate

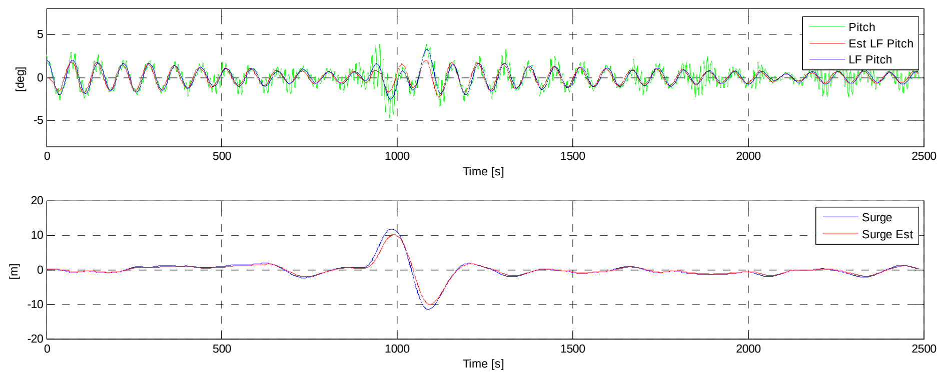

Figure 11 Pitch and surge position

Note the following color scheme for pitch and position variables:

Green	Measured value
Red	Estimated low frequency value
Blue	True low frequency value
Magenta	Estimated wave frequency * 10

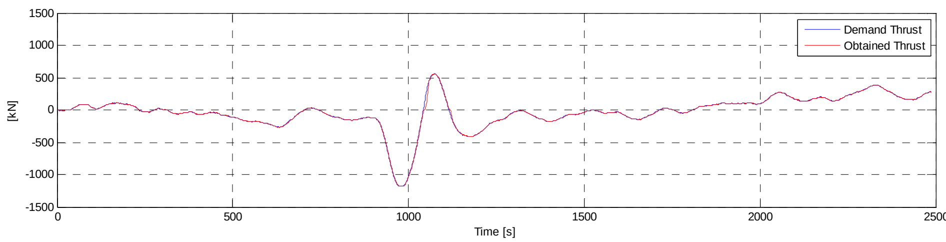

Figure 12 Thruster demand and obtained thrust

DP control with pitch rate feedback

Low frequency pitch rate control is applied.

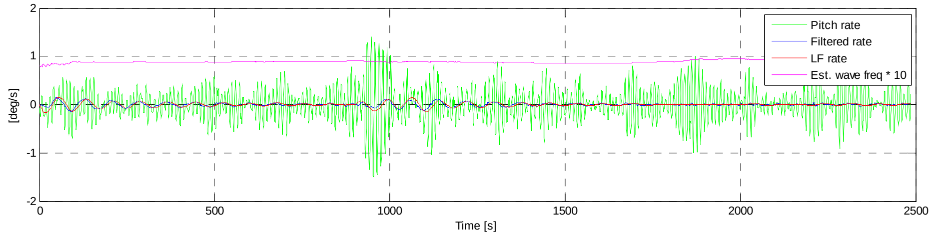

Figure 13 Pitch rate

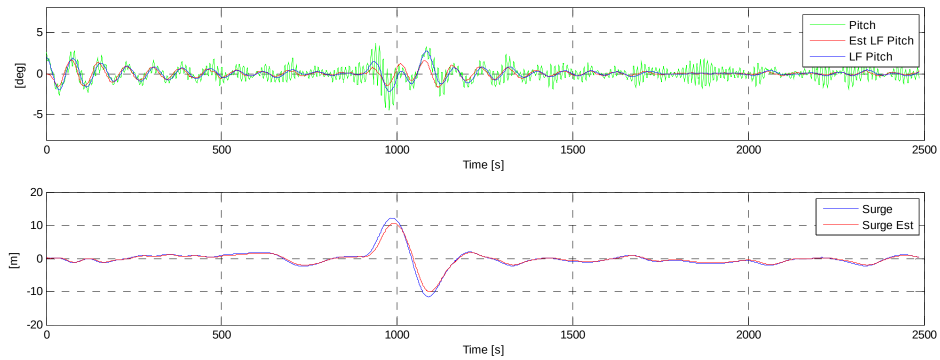

Figure 14 Pitch and surge position

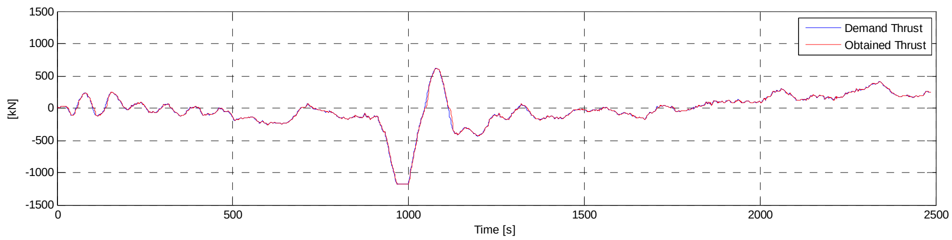

Figure 15 Thruster demand and obtained thrust

The gain for the pitch rate control must be selected carefully. A too high gain will influence the surge motion in a negative manor which also increases the pitching. See figure below.

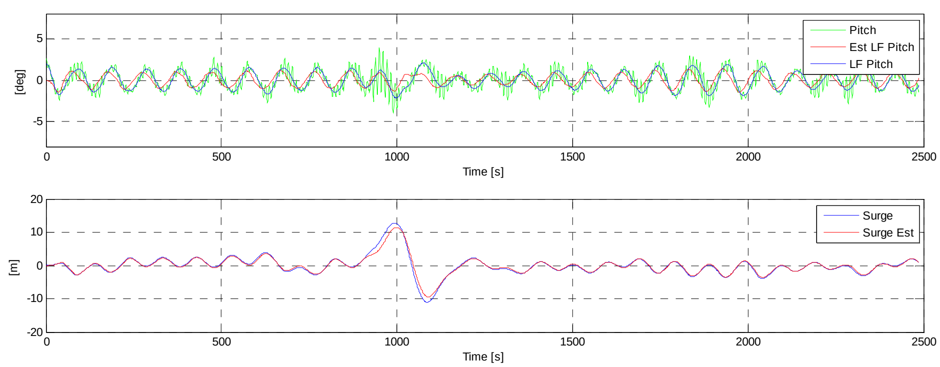

Figure 16 Pitch gain x 10

Observations

As long as the pitch rate control is satisfactory tuned the overall pitching can be reduced. An improvement of about 10 times in relative damping should be feasible for the low frequency pitching, i.e. at vessel's natural pitch period. No improvements can be expected for the wave frequency component.

The pitch rate control has no significant impact on station keeping. The pitch rate control does not require significant additional thrust. The thruster forces for the cases above are shown in the figure below.

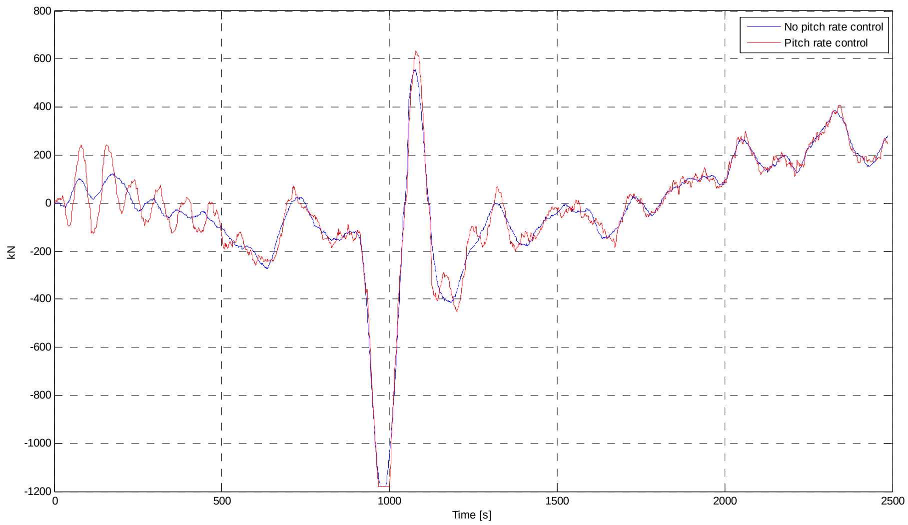

Figure 17 Thruster utilization

In the event of a sudden external excitation the pitch rate control can not significantly improve the first transient pitching immediately but will dampen the effect over time. See figure below.

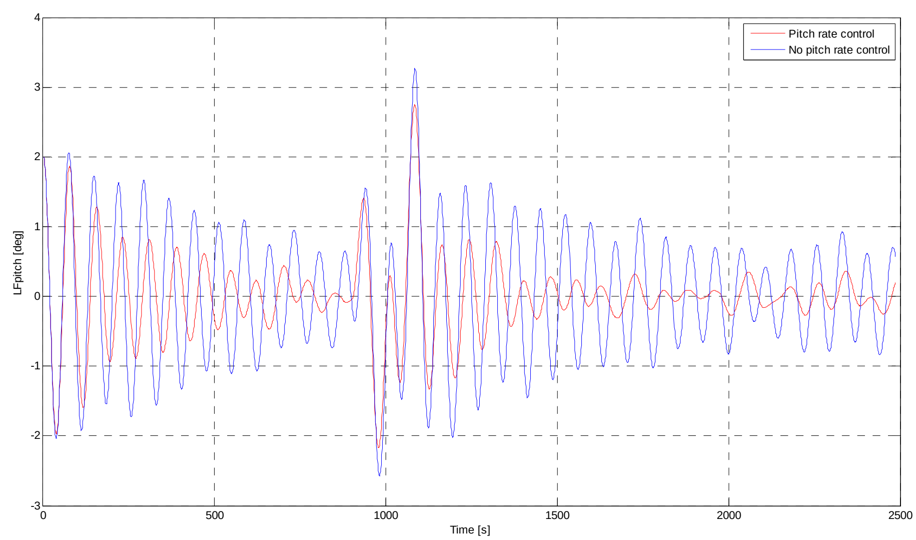

Figure 18 LF pitch with and without rate control

Conclusion

The paper demonstrates that the pitch/roll damping using thrusters can reduce the overall low frequency (the vessel's natural oscillation frequency) pitch/roll motions of semi subs.
Unfortunately it can not significantly reduce the effect of extreme sudden excitations immediately, but will improve the settling.
The wave frequency component of pitching and rolling can not be mitigated.