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ADVANCES IN TECHNOLOGY

DP Control on DEP
(Diesel Electric Propulsion) Vessels

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ABSTRACT

The "Reliability of DP Operations in Deep waters" is a joint industry project aiming at increasing the operational reliability of DP operations in deep waters. The project has focused on reference systems, how to handle them and on operator support tools. Several new products and functions have been developed during the project. In this paper, the newly developed position reference system handling and extended Kalman filter estimator are presented together with test results from an offshore test.

INTRODUCTION

DP systems play a more and more important role in deep-water operations. The DP performance is generally focusing more on reliability of the overall operation rather than on accuracy in station keeping. This implies that the performance of both the vessel and its different kinds of equipment (like power plant, thrusters and auxiliary systems) as well as the DP system and its reference systems and sensors must be taken into account when assessing the performance.

A new *extended Kalman filter* estimator for DP system was developed to improve performance and increase robustness to reference system error and noise.

To verify the performance of the new estimator compared to earlier version of DP system, an offshore test was performed. The results of this offshore test will be presented with focus on:

- Positioning accuracy.
- Reduced thruster wear and tear.
- Reduced power usage.
- Robustness to reference system error and noise.

REFERENCE SYSTEM PROCESSING

In deep waters far away from any fixed installations the availability of different types reference systems are quit limited. So far only dGPS, LBL acoustics and the Simrad HiPAP are available as reliable reference systems. The dGPS system is quite accurate, but is corrupted by coloured noise which cannot be filtered, the noise level is, however, quite satisfactory. The LBL acoustic systems have very good accuracy, but the sound transmission in water and transponder delays to prevent sound collisions at the reception in the transducer, reduces the data rate of position fixes to the DP system quite dramatically compared to the general case in more shallow waters. The HiPAP has a good noise level with close to white noise characteristics (high frequency). It can supply a higher data rate than an LBL system since only one transponder is used at a time. To get the best possible positioning, it is therefor necessary utilise the best qualities of each one. This can be done by using Kalman filtering techniques.

The Kalman filtering based DP controller used in the Simrad DP system is shown in figure 1. The main issue in the deep-water context is the model updating from reference system readings.

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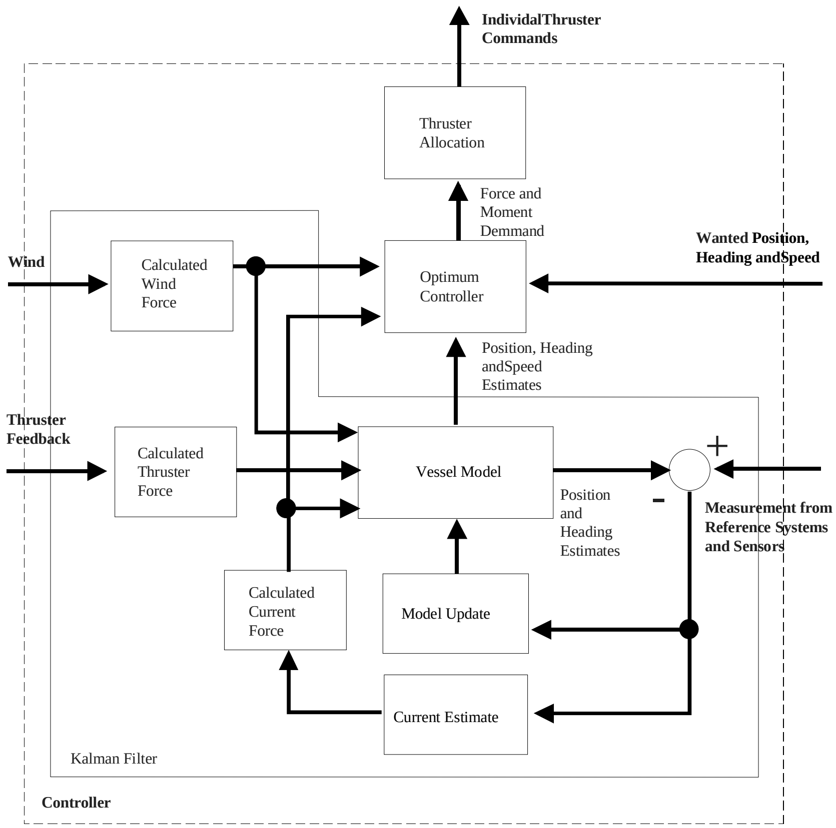

Figure 1 Kalman filter based DP controller

When combining LBL acoustics with dGPS, the Kalman filter will stick to the dGPS since this system has low high frequency noise characteristics and the highest data rate. The LBL will be assessed as noisy. The situation is illustrated in figure 2.

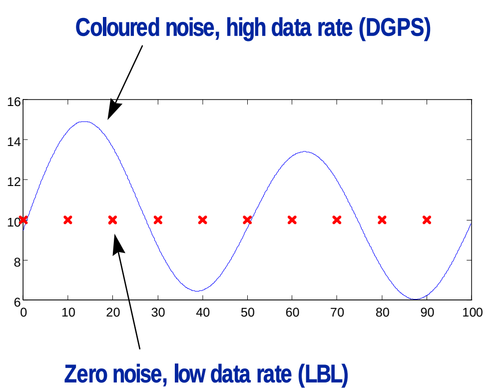

Figure 2 Coloured noise problem

To improve this, the knowledge of the noise characteristics of the two systems must be taken into account.

Solution:

- Utilise knowledge of nature of reference systems
    - Quality figures from reference systems
    - Monitor high frequency noise statistics (fast Fourier analysis, FFT)
    - Perform complete Kalman filtering calculations
- Kalman filter gains depending on
    - accuracy of position estimates
    - measurement noise
- Reference system mixing according to combination of
    - noise figures from reference systems
    - high frequency noise statistics

Some dGPS receivers can produce estimates of its accuracy in terms of variance of the position data. The quality figure is based on satellite geometry and validity of differential corrections. LBL acoustics may produce uncertainty ellipse according to the vessel position and geometry of transponder array as well as signal to noise ratio. Because the way of processing the data inside the HiPAP system, it may also estimate its own accuracy from internal measurements of the signal to noise ratio.

In the DP system the innovation signals, i.e. the difference between measurements and model prediction, are good measures of the accuracy of the reference systems (with respect to high frequency noise). By using FFT technique very sharp frequency cutting may be performed, and hence the high frequency component of the noise level (above 0.1 Hz) can be estimated. A typical FFT output is shown in figure 3.

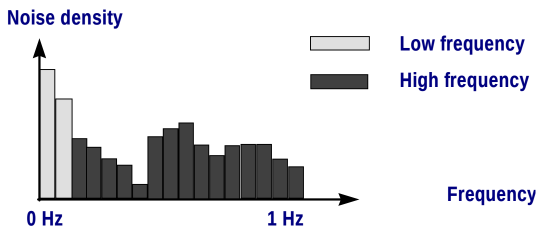

Figure 3 FFT analysis

By combining accuracy data from the reference systems themselves and the statistical analyses of the innovation signals a more complete picture of the quality of the reference systems may be derived.

The accuracy of the position estimate in the Kalman filter plays an important role in the DP controller. The accuracy of this estimate will be driven by the accuracy of the measurements. In addition there is an inherent inaccuracy of the mathematical model of the vessel, which will decrease the accuracy if no measurements are received. To optimise the utilisation of the reference position fixes the estimated accuracy of the position estimates within the Kalman filter must therefor be taken into account. The Kalman filtering technique has a set of mathematical formulas for handling this, known as the Riccati equations.

Figure 4 below shows a typical example where dGPS and LBL acoustics are combined. dGPS has its typical coloured noise characteristics (assumed time constant in this example). Initially dGPS is assumed to give OK signals, and the uncertainty of the position estimate will become steady. Each time an LBL fix arrives, the uncertainty of the position estimate is reduced because the accuracy of the acoustics is assessed to be better. The position uncertainty will, however, increase again because the dGPS accuracy is lower. At the end it is assumed that no reference systems are giving OK signals, and hence the uncertainty of position estimate grows very rapidly because of inaccuracies in the vessel model. In the Kalman filter updating, gains are increasing by increasing uncertainty of the position estimate. When new measurements arrive at a later stage, high gains will be used until they converge to the stationary condition shown at time zero in the figure. LBL updates use high gain because of its good quality. dGPS gain is reduced due to its coloured noise characteristics.

The estimate uncertainty of the position estimate plays also an important part in error checking of position readings. The innovation signal for each reference system is compared to an acceptance limit derived from this estimated uncertainty of the position estimate. Hence the better the quality of the estimated position, the tougher the failure limit, and vice versa.

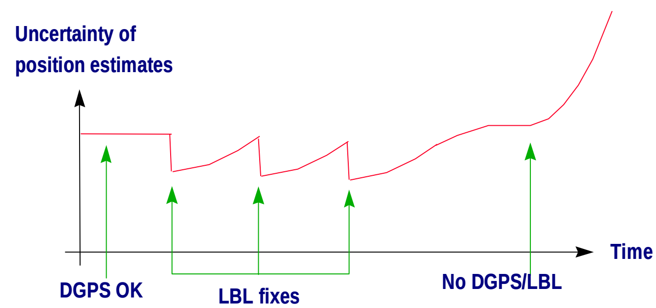

Figure 4 Uncertainty as a function of time

Offshore Test

The main objective of the offshore test was to verify and demonstrate the functions developed in the project under realistic environmental conditions and in deep water. Position reference system test consisted of introducing several failures to the position reference systems, and changing update rates, while the vessel was on DP control. The estimator test consisted of both static and dynamic tests, where the vessel was moved in a programmed pattern while the position accuracy, thruster and power usage were recorded.

- Compare with standard DP estimator Provoke errors, noise and drop out in position measurement systems
- Robustness in general
- Reference system redundancy handling
- Robustness to data update rate
- Power consumption

The test was performed onboard MSV Botnica.

MSV Botnica is used as an icebreaker in the Baltic Sea in the winter season and as a multi-purpose offshore vessel in the North Sea in the summer season.

Figure 5 MSV Botnica

Test results

Position reference system handling

Observations during the position reference tests:

- Less thruster modulation, i.e. better filtering without additional phase lags when using the new position reference system handling.

- The Kalman gain adapts to the position reference system update rate and noise level. Update rates up to 10 seconds were successfully tested with the new estimator. The standard estimator did not perform as required at this slow update rate.

In the figure below, the Kalman position gain K_x is plotted as a function of time. Data rate for dGPS2 was reduced from 1Hz to 0.5 Hz at time 540s. The gain increased for both systems. At time 1400s the dGPS 2 was disconnected from the system. The gain for the remaining dGPS 1 increased as required. The positioning was not affected during this test.

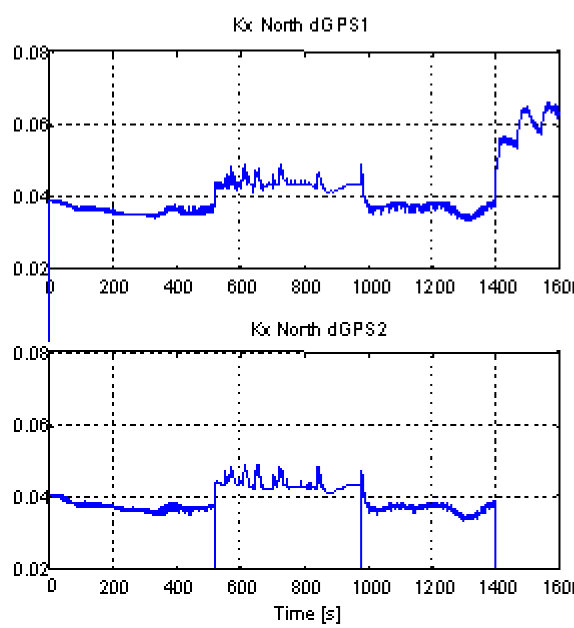

Figure 6 Adaptive Gain

Estimator test

The test consisted of an initial 15 minutes station keeping with movements in alongship and sideways axis with 15 minutes of stabilisation periods between the movements. The movements were carried out with 0.3 m/s speed setpoint and with 20 meters and 40-meter movements.

The following parameters was recorded and analysed:

- Position overshoot and stability
- Heading stability
- Thrust consumption
- Generator load
- Thruster power usage
- Fuel consumption

The alongship position during the test with the standard estimator is shown in figure 7 as a time series plot. The environmental conditions during this test was 20 knots wind, sea current of about 2 knots, sea state 3 with some long periodic swell from a recent storm. The time scale is in seconds.

In figure 8 the same test is repeated with the new estimator. The performance is increased with reduced overshoot after the position movement, and the increased stability.

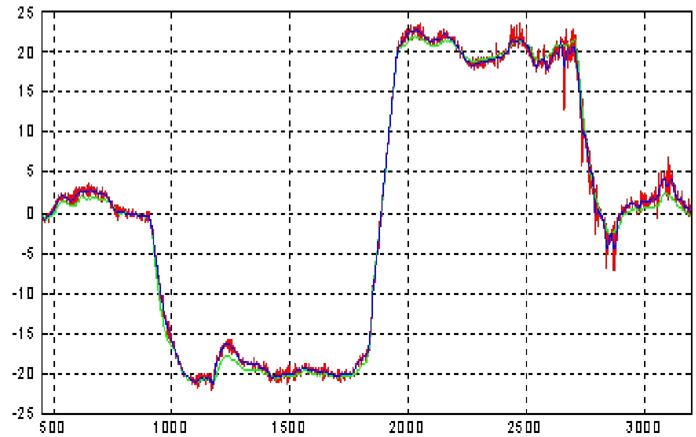

Figure 7 Alongship Positioning using Standard Estimator

Figure 8 Alongship Positioning using New Estimator

(red) Position Measurement
(blue) Filtered position measurement
(green) Estimated position

The figure scale is meter along the y-axis and seconds along the time axis.

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Low Position Update Rate

In order to test the estimator adaptation to data rate, the data rate for dGPS 1 was reduced down to one position update each 5 seconds. The vessel vas moved in alongship axis in the same manner as for the test above.
As can be seen in figures below, the the performance increased. when using the new estimator with slow update rate.

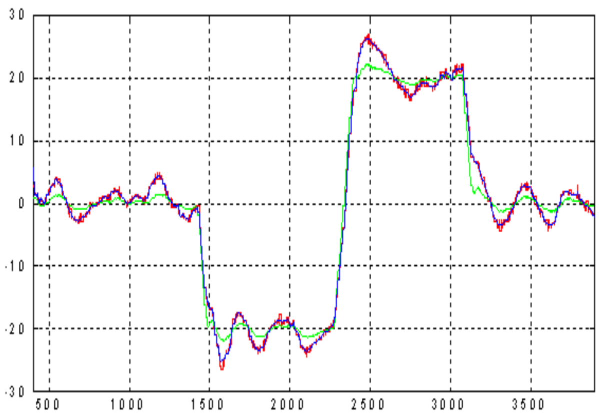

Figure 9 Alongship Movement Standard Estimator

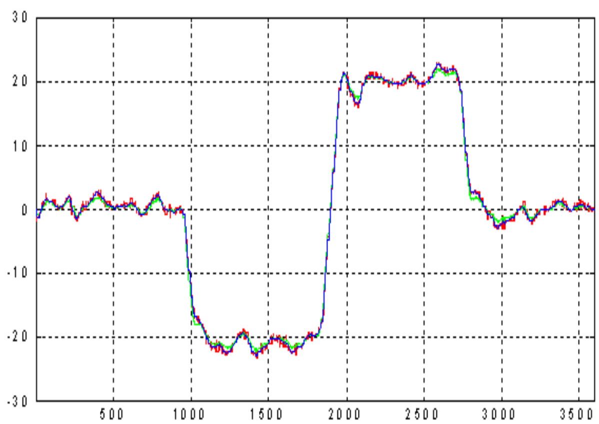

Figure 10 Alongship Movement New Estimator

During this test, the sideways position should be kept constant. The plots below show a time series plot for the sideways position for the standard and new estimator. The standard estimator shows some sign of instability, whereas the new estimator performs within limits.

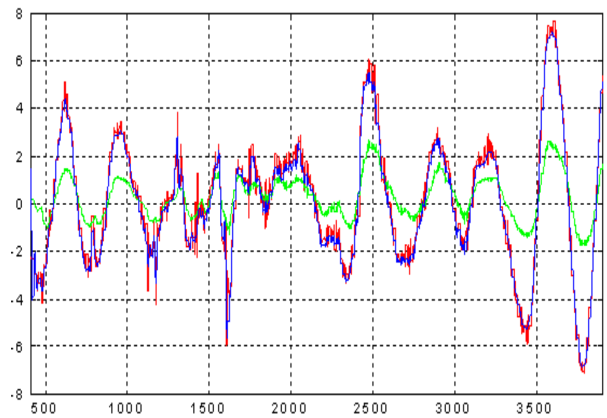

Figure 11 Sideways position Standard Estimator

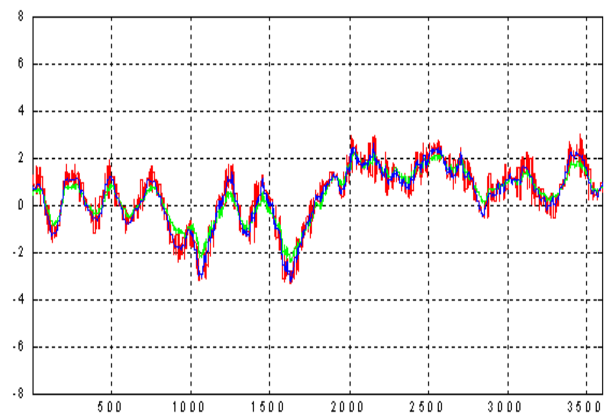

Figure 12 Sideways position New Estimator

Power Consumption

Three comparative offshore tests was performed whith the standard and the new estimator. During the tests, the power measurements from the generators, power measurement from the thruster motors, and the fuel consumption were measured.

The Dynamic power is calculated by subtracting the idle power from the tunnel thrusters.

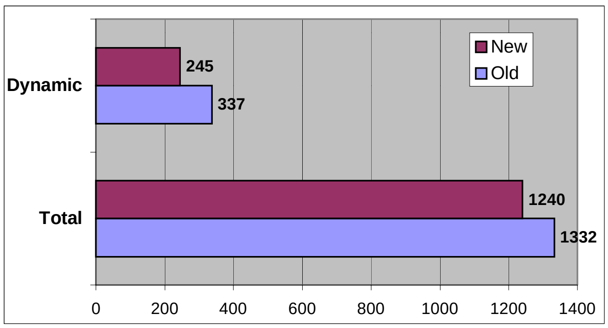

Figure 13 Power Consumption [kW]

Total power reduction = 6.9%
Dynamic power reduction = 27.4%
Measured total fuel reduction = 5%

Thruster wear and tear

The accumulated movement of the pitch servo for the tunnel thrusters was recorded during the tests.

When using the new estimator, the pitch servo command changes were reduced with 30%.

Conclusions:

- Reduced power consumption and thruster wear and tear.
- Successful adaptation to changing position reference noise.
- Test with low data rate for position measurements demonstrated the advantage of the new estimator's ability to adapt to varying data rates.