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Operational support by controlling ship motions (DP Plough operations)

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Abstract

The purpose of any DP control system should be: supporting/serving the main vessel operation. Plough operations performed by a vessel require certain functionalities from a control system in order to be able to fulfill the operational needs while taking into account safety measures. The first step is to identify functionally different operational situations of a plough operation from a ship motion control point of view. After this identification of the different operational situations, a proper approach for each situation has to be defined. This paper will discuss the implementation of the so called DP plough module which is able to recognize a certain operational situation and to translate the required approach for that situation into algorithm adjustments of one of the already present functional blocks within a DP control system (Estimator, Controller and allocation). This paper will also touch on the results as this DP plough module has been implemented on board and is currently being used.

Introduction

The purpose of a DP control system should be: supporting the operator, with this mind set one should design a (DP control) system. During a ploughing operation a DP control system can be used in order to accurately follow a certain track which is desired from an operational point of view. Several stages / operational situations can be distinguished from a ship motion control point of view, different operational situations require different approaches in order to obtain the optimal result related to the ploughing operation (as fast as possible / as safe as possible). An important aspect is to keep the operator in the loop that is the operator should be informed by the system in what operational situation it is, as each operational stage comes with its specific behaviour.

(DP) Plough operations

During operations the plough is dragged over the seabed in order to smoothen previously dredged areas as illustrated in Figure 1.

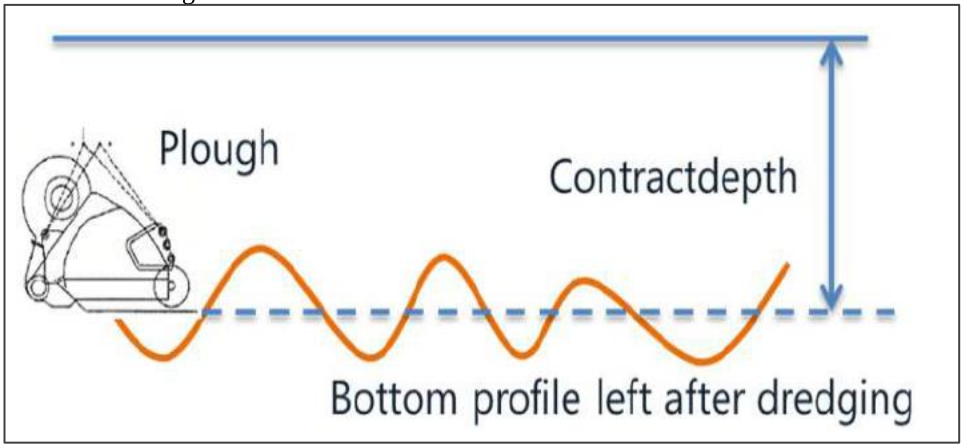

Figure 1 Illustration Ploughing

The irregular bottom profile will result in irregular forces/moments acting on the vessel attached to the plough.

Plough operations in the ship motion control domain

A DP system has as main purpose to keep a vessel station or to move a vessel along a predefined track. This is obtained by making use of the vessels own propulsion. The DP control system is a control system which consists of three main function blocks:

1. Estimator
2. Controller
3. Allocation

Each of these blocks has its own functionality and is dependent upon a (correct) physical/mathematical model of the vessels dynamics. During ploughing the plough forces/moments acting upon the vessel will have a considerable impact upon the vessel dynamics, as such these forces/moments should be taken into account. Within this document a plan of approach will be described regarding taking into account the plough forces/moments such that satisfactory/optimal behavior is obtained during plough operations in the DP modes. Prior to implementing the plough forces into the DP control system a functional distinction has to be made in the different operational situations, as each situation requires its own approach.

Plough operational situations
The main operational situations related to the DP control system, will be primarily defined based upon the magnitude/frequency of the plough forces.

Situation 1:
The thrusters can produce a counter force in relation to the plough force and the vessel can maintain track with desired speed:
- Thrust wise (amount of kN)
- Frequency wise (ramp-up and ramp down times, thrusters are able to follow the fluctuations of the plough forces

Situation 2:
The thrusters can produce the average counter force required (magnitude wise) and the vessel can maintain track with desired set speed, however the thrusters cannot follow the plough force demand frequency wise

Situation 3:
The thrusters cannot produce the required average counter force and the vessel cannot maintain track with the desired set speed, however by decreasing the desired set speed, the vessel can maintain track.

Situation 4:
The thrusters cannot produce the required average counter force and the vessel cannot maintain track with the desired set speed, average plough forces/moments indicate that the plough is stuck.

Situation 5:
The roll momentum caused by the plough operation (set speed, set heading/course) is beyond its acceptable limits

Strategy plough forces/moments implementation

Based upon the operational situation actions have to be taken within the DP software.
A specific plough operation module has been designed in order to integrate the plough forces/moments into the DP control system.

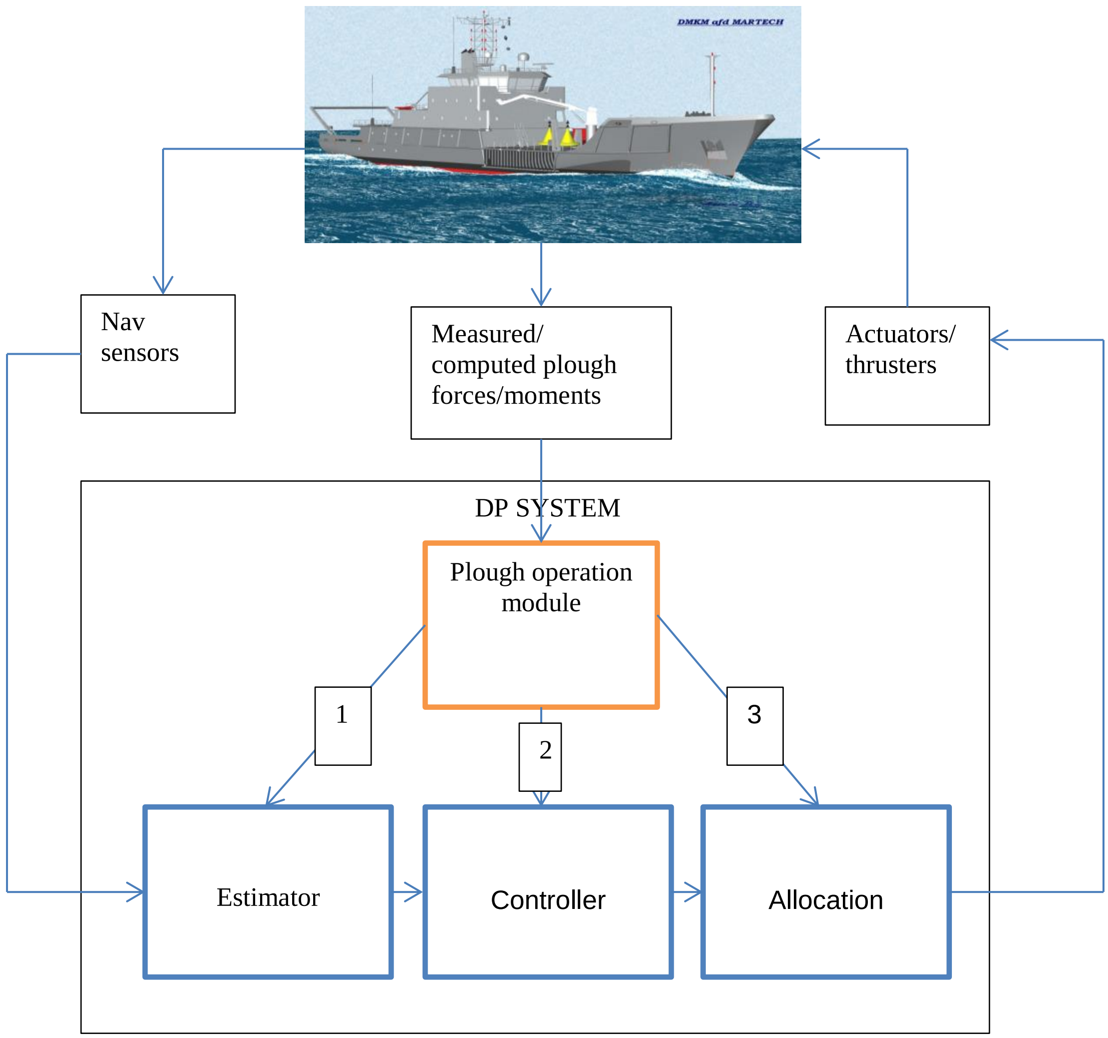

Figure 2 Plough operational module architecture

Functional description plough operation module
The plough operation module has a number of functions:

Module specific
1. Filtering and averaging of the measured plough forces/moments
2. Determining the situation of the plough operation (mentioned situations)

Estimator/filter specific
3. Adjusting estimator/filter gains (which effects to which extent nav. sensor information is taken into account when estimating the state), based upon the plough forces/moments

Controller specific
4. Adjusting P,D gains for the controllers, (partly based on the situation of the operation)
5. Adjusting the total control demand(s) based upon the phase of the operation and upon the frequency of the filtered/averaged plough forces/moments
6. Adjusting the SOG setpoint based upon the situation of the plough operation
7. Switching Control mode from track sailing to position keeping

Operator in the loop
Based upon the detected situation the operator should be informed.
That is:
Situation (3) → Where the function (6) adjustment of set speed is activated
Situation (4) → Function (7) is activated → Switching control mode
Situation (5) → The roll momentum is beyond its acceptable limits, (possibly activating function (6) and/or (7)

The operator should be informed in case the Fx and Mz, are within acceptable levels however the Fy, is beyond its expected values. (Indicating that the plough is not properly aligned with the vessel).

Software architecture description Plough operation module / short elaboration
1.Estimator
Input plough forces/moments into the Estimator
a) When the plough operation module is active, the plough forces/moments will be fed into the estimator of the surge/sway and yaw movement in order to obtain a better estimation of the states of the vessel. / This will be done in all situations in order to improve the control actions, as the control actions are based upon the estimated states. Improvement of the control action, leads to improvement of control performance.

Adjust estimator gain(s)
b) Based upon the (averaged) magnitude of the plough forces/moments, the estimator gain(s), can be adjusted. / The estimator gains determine to what extent the measured nav. sensor data is taken into account within the estimation of the vessels states. The estimation of the vessel states is a combination of nav. sensor data and a mathematical/physical model of the vessel dynamics. When relatively high plough forces/moments are applied to the vessel the assumed mathematical/physical model might differ from reality. In this case one could adjust the estimator gain in order to have a better estimation of the vessel's state.

2.Controller

Feed forward plough forces/moments

a) Based upon the (averaged) magnitude of the plough forces/moments a filtered/averaged value can be fed forward into the controllers. To what extent these forces/moments are fed forward can be regulated by the plough operation module, based upon for instance available thrust power

Automatic gain control

b) In case the thrusters are not able to follow the control demand, (frequency wise), (situation 2) the desired control action can be reduced such that no extra phase delay is build up, and such by implementing this (automatic gain control) instability issues due to situation 2 will be reduced. The concept of automatic gain control is introduced in ref[1].

Adjustment Damping

c) Change of ,D values (Increasing of D value,) based upon the (averaged) magnitude of the plough forces/moments. The P,D values used in the controllers are model based. When large plough forces/moments are exerted upon the vessel, the P,D values based upon the assumed model might be suboptimal. When large forces/moments are exerted upon the vessel, this will result in large speeds of the state (surge speed, sway speed, heading rotation speed). Controlling these states should be primarily focused upon damping the speeds of the states.

Adjustment speed setpoint / mode change

d) It could occur that the plough is stuck. In this case the requested SOG setpoint should be reduced, next to that the system should switch from Track sailing mode (DT-slow) to Position keeping mode (DP Auto) if required.

3.Allocation

The implementation of the interface between the plough operation module and the allocation function has not been implemented, as such this is left out of the scope of this paper.

Conclusion

By adapting the operation orientated design approach a plough operation module has been successfully implemented in a DP system which is actively used by the crew. By acting differently in different operational situations, (as going automatically into the hold position mode) the DP system is also supporting the operator when conditions change, as in these cases the system will automatically react/act upon the operational situation, instead of awaiting for an extra operator command.

References

[1] J. van Amerongen, P.G.M. van der Klugt, H.R. van NAUTA LEMKE, "*Rudder Roll stabilization for ships",* Automatice, Vol. 26, No. 4. pp 679-690, 1990

[2] IMCA DP station keeping Event Bulletin 04/16, November 2016

[3] E. El Amam, "*Efficient operational support by controlling ship's motions*", 3th Dynamic Positioning Asia conference & exhibition, Singapore 2013