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AdaNav - a modular control and prototyping concept for vessels with variable gear configurations

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Abstract: According to their tasks and relations, specialized vessels are equipped with modern steering devices like podded drives or thrusters. Such modern steering concepts substantially increase the manoeuvring capability of the vessels. However, mates are not able to handle those gears efficiently, because the relations between action and reaction are far too complex. Automation is needed to support the steering team. The industrial production of wheelhouse systems within the large spectrum of types of manoeuvring gears and their location on vessel hulls is still a hard problem. Finally, each adaptation for the navigation and track guidance system looks like an individual system production. For an easier prototyping and implementation of different steering concepts in navigation and track guidance systems for vessels, a modular concept has been applied by the University of Rostock, Center for Marine Information Systems (CeMarIS). Supported by the Federal Ministry of Economics and Technology, in the joint project "Adaptive Navigation System for Ships" the control of each device was implemented into a new automation strategy for the guidance process to realize an optimal manoeuvrability in motion. At the end of the project, final tests in the Maritime Simulation Center in Warnemünde (MSCW) have demonstrated the efficiency of the developed modular control concepts.

Keywords: Ship control, Force control, Torque control, Prototyping, MIMO

1. INTRODUCTION

In the development of modern ship guidance systems two trends face each other. The ship and engine design engineers develop greater and more efficient power engines and steering aggregates to obtain strong transverse thrust. Depending on the operational area and the intended tasks, the number of inserted components can reach a considerable size. Then, so called dynamic positioning (DP) systems will charge the control. However, due to their construction, their use is limited to low speed. Fig. 1 and Fig. 2 show the ferry vessel "Schleswig-Holstein" of the shipping company Scandlines Germany GmbH with really four of those podded drives. Fig. 3 shows the main control platform of the multipurpose vessel (m/v) "Arkona" of the WSA Stralsund. This picture shows a typical control situation, which is hard to manage. The acting degree of freedoms of the two astern PODs and front waterjet drives, in each case two for thrust and direction, are restricted in manually navigation mode (elimination or parallel operations). In addition to the actuators, more precise navigation sensors are available, which in principle

Fig. 1. Ferry vessel with four podded drives, photo Scandlines archive

allow higher steering quality while driving with integrated guidance systems. However, present navigation systems are far away from those goals. Their track guidance systems are based on simple mathematical models for ships with conventional propeller-rudder combinations from the

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Fig. 2. Double pusher propeller aggregate of the ferry vessel "Schleswig-Holstein", photo Scandlines archive

Fig. 3. Port wing control platform of the m/v "Arkona", photo H. Korte

late 50's, Nomoto et al. (1957). Though modern steering aggregates can be attached at any place of the vessel hulls, their consideration during the construction phase is not possible by using Nomoto models only. This is not satisfying for the industrial serial production. Nowadays, we observe an increasing manoeuvring capability for ship navigation as well as a decreasing development and service expenditure for the manufacturing of integrated navigation systems. Although the theory and application of advanced control concepts for modern vessels has been established, see e.g. Fossen (2002); Nebylov (2004); Perez and Fossen (2007), the practical realization is still not widely accepted, as can be verified by the description for track guidance systems based on ordinary autopilots, e.g. Kongsberg, NACOS, TRANSAS. In order to bridge over this gap, the German Federal Ministry of Economics and Technology (BMWi) started the joint research project "AdaNav - adaptive navigation system for ships" with the partners SAM Electronics Hamburg, Rheinmetall Defence Electronics Bremen, University of Wismar (Department of Maritime Studies and "Schifffahrtsinstitut"), and the University of Rostock, Center for Marine Information Systems (CeMarIS), which was responsible for the subproject "Modular Control on Ships".

2. MODULAR CONTROL CONCEPT

Commercial track guidance systems are conventionally constructed by a cascaded design of subordinated heading (direction), and for superior track (distance at right angle) controllers, which use the model background of a slim rigid body. The movement is assumed to be restricted on the water surface, Majohr (1985). Applying the linear balance of forces and moments, after restriction to small deviations near an operating point and transformation into the Laplace domain, we obtain plant models of second order for the speed components $x_k(s)$ as functions of the acting variables $u_l(s)$. For instance, the transfer function of the course rate $r(s)$ as response to the rudder angle $\delta(s)$ is described by

$$F_{r\delta}(s) = \frac{r(s)}{\delta(s)} = \frac{K_{r\delta}(1 + sT_{Dr\delta})}{(1 + sT_{1r\delta})(1 + sT_{2r\delta})}\,. \qquad (1)$$

The parameters T_{Dkl} and K_{kl} in the different transfer functions $F_{kl}(s)$ for the speed components in relation to the corresponding acting elements depend on the speed and on the loading conditions of the ships, and they correlate strongly to each other. A simplification by cutting the Taylor expansion behind the linear element does not remove these correlations, which lead to honest problems for the parameter identification in practice. The special structure of transfer matrices for MIMO processes are investigated in Rosenwasser and Lampe (2006). AdaNav pursues the following approach. The model equations and their parameter assignment should be adapted to different steering concepts and configurations without strong effort. The first idea consists in unifying the discrepancies of various inputs already in the speed cascade. Therefore, the motion equations are split into auxiliary quantities, which can be independently developed from the m control and the n state variables. This is the fundamental idea behind the state space concept, where we write the state progress in the form

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}.$$

Assuming that the surge velocity u is independent on the sway velocity v and yaw rate r, the linear model for the example above takes the form

$$\frac{\mathrm{d}}{\mathrm{d}t}\begin{bmatrix} u \\ v \\ r \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & a_{23} \\ 0 & a_{32} & a_{33} \end{bmatrix}\begin{bmatrix} u \\ v \\ r \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \\ b_{31} & b_{32} \end{bmatrix}\begin{bmatrix} \delta \\ T \end{bmatrix}. \qquad (2)$$

This model has two important properties. At first, it has a minimal number of parameters. This feature is necessary, when we want to identify the parameters in the matrices of (2). Secondly, the model distinguishes between inner and outer causes for the motion. The inner causes depend on the states of the ship motion. The corresponding parameters a_{ik} depend on the ship hull, load, and the water around. The outer causes issue from the drives, thrusters and external disturbances like waves, wind and current. From the physical point of view, equation (2) states the equilibrium of forces and moments. Hence, the matrix $\mathbf{B}$ transforms the real control actions $\mathbf{u}$ to the auxiliary (virtual) control action $\boldsymbol{\eta}$: