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# AUTOPILOT WITH ADAPTIVE VESSEL MODELLING

## ABSTRACT

A feasibility study of an application of adaptive model in a ship autopilot is presented. The system for predicting a ship motion, developed in the previous studies, was enriched by a control algorithm of the ship motion and the adaptive model of the ship. The signals from the navigation sensors (DGPS, log, and gyrocompass) are filtered by dedicated Kalman filters, and then processed by an integration algorithm to obtain the best estimation of the actual ship position, heading, velocity and rate. These data form the state vector of the ship dynamic model. The model of the ship dynamics has parameters which are identified on-line using particle filter method. The efficiency of applied control methods and collaboration with on-line adaptive dynamics modeling was verified by simulations.

**Keywords**: Autopilot, Vessel Modelling.

## INTRODUCTION

In many modern vehicles a support to the operator is provided by automation systems. These systems may be of various complexity, from simple warning devices like an audio signal indicating approaching to the obstacles to automatic systems performing selected manoeuvring or systems, which take over the vehicle control in an emergency.

The simulation model of an advisory system for sea vessels was developed in [1] and [2]. The advisory system was composed of the models of sensing devices, the filtering of individual sensor signals, integrating algorithm for the best estimation of vessels state vector (using signals from navigation sensors), adaptive vessel modelling and predicting its future motion.

In the next studies the autopilot for track and velocity control [3] was added to this system.

This new functionality raised questions of the system efficiency and its robustness to external disturbances. This issue was investigated in the study reported in this paper.

## SYSTEM MODEL

The captain / pilot advisory system with autopilot is composed of three main subsystems: the sensor data collection and processing, the identification of model coefficients and control of the velocity and track. The part performing signal processing and predicting future vessel motion is shown in Fig.1 [1].

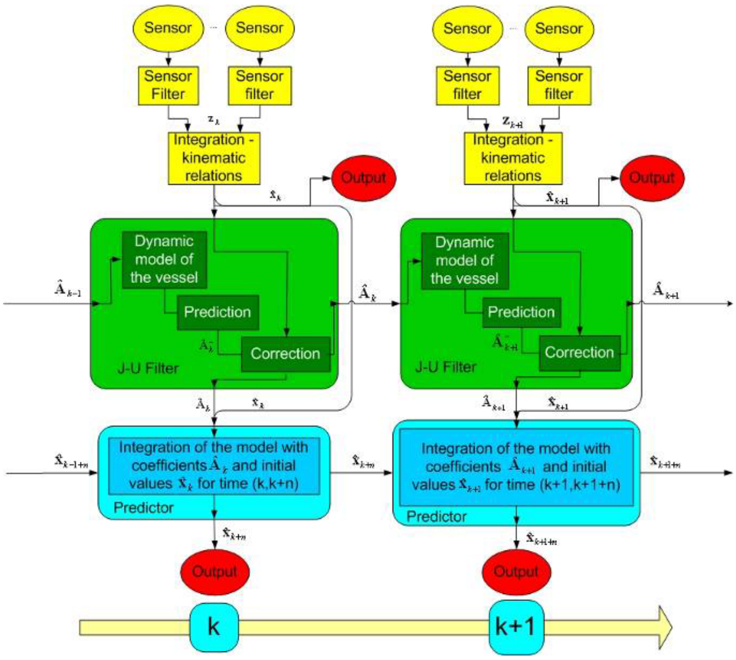

Fig. 1. General scheme of the system for prediction of ship motion

The subsystem of navigation data collection is composed of log, DGPS receiver, and gyroscopes measuring heading and angular rate. Signals from the sensors are filtered individually by Kalman filters. The data from various sensors are integrated to obtain the best estimate of the vessel state variables, using Kalman filter based on the model of vessel kinematics.

The subsystem of identification of the vessel model calculates the assumed parameters of the system model. For identification of ship model parameters the Julier-Uhlman filter is used. In this filter the ship dynamic equation of motion form the observer model and the identified parameters are the state variables.

The predicting of the future ship motion is done by solving numerically the ship equations of motion for the assumed time period, keeping constant control variables.

The model of ship dynamic has three degrees of freedom: longitudinal and transversal velocity and rotation about the vertical axis. The expressions describing inertia (apparent masses), hydrodynamic and aerodynamic loads contain unknown parameters identified by filtering algorithm. The details of the model are given in Annex 1.

The sample results of predicting the ship motion are shown in Fig.2 [1]

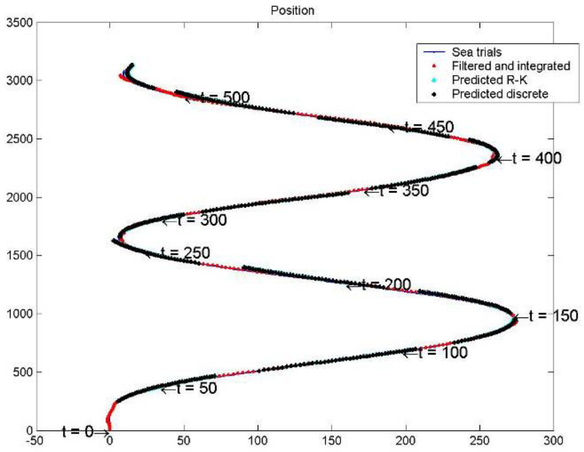

Fig.2. Prediction of the vessel motion in zig-zag test [2]

An autopilot was designed to keep the assumed ship track and velocity relative to the ground. The structure of the autopilot is shown in Fig 3, and the sample control results in Fig.4. In controlling the track and velocity various PID configurations were tested, and the simple P regulator appeared to be the most efficient. In Fig 4 an influence of wind, current and wind with current on the track control is presented.

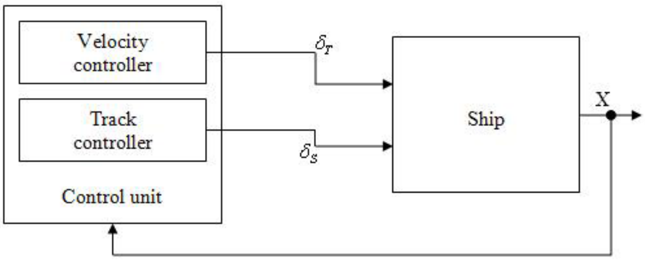

Fig.3. General structure of ship autopilot

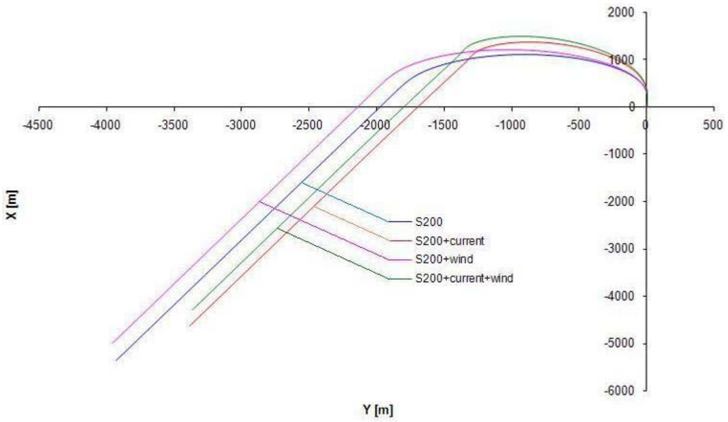

Fig.4. Influence of wind and current on autopilot control efficiency

In the subsequent system development the on-line identification of the ship motion was included into algorithm. The structure of the actual system simulation model is shown in Fig.5.

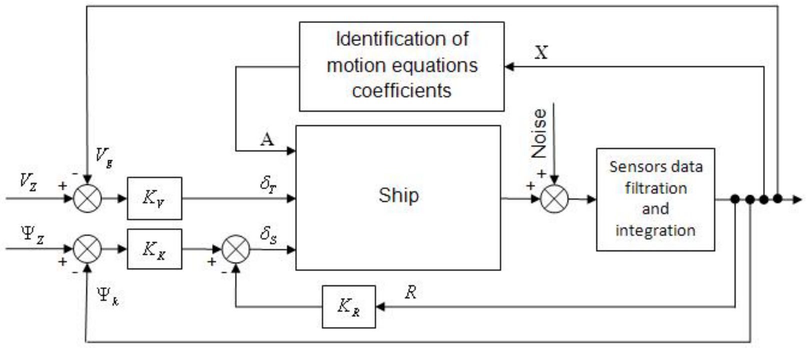

Fig.5. The structure of autopilot with adaptive vessel model

The block "ship" included the 3DoF vessel dynamic model. The block "sensors data filtration and integration" contains the models of sensors, individual sensor signal filtering and integration algorithm for the best estimation of the vessel state vector. The external disturbances are modeled as white noise with assumed magnitude. The block "identification of motion equation coefficients" contains Julier-Uhlman filter calculating the best estimates of parameters of equations of motion.

In Fig.6 the results of the 60º of track variation are presented. For assumed disturbances acting on the system the ship keeps assumed track.

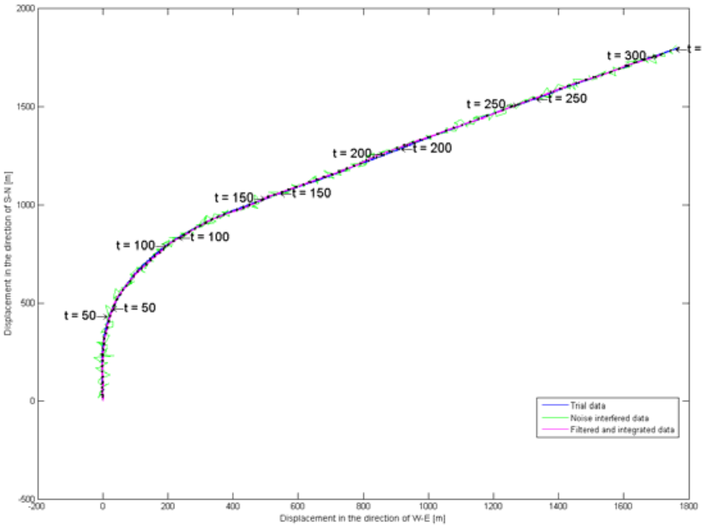

Fig. 6. Track variation with external disturbances acting on the sensor data

## CONLUSONS

The actual structure of the system contains modules for signal data filtration, navigation signal integration, identification of the parameters of the ship model, autopilot with track and velocity controlling functions and predicting of the future vessels motion. Each module was tested individually and within the whole system. The complete system performs well, and as might be expected its efficiency depends on the magnitude of eternal disturbances. The validation against the see-trials data is needed for completing system evaluation.

## ACKNOWLEDGEMENTS

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## ANNEX 1

The vessels equation of motion

$$
\begin{aligned}
&\begin{bmatrix} (m_h+\lambda_{11})\dot{u}-S_y\dot{r} \\ (m_h+\lambda_{22})\dot{v}+(S_x+\lambda_{26})\dot{r} \\ -S_y\dot{u}+(S_x+\lambda_{26})\dot{v}+(I_{Hzz}+\lambda_{66})\dot{r} \end{bmatrix}+\begin{bmatrix} -(m_h+\lambda_{22})vr+(S_x+\lambda_{26})r^2 \\ (m_h+\lambda_{11})ur-S_yr^2 \\ S_yvr+\lambda_{22}uv-\lambda_{11}uv+(S_x+\lambda_{26})ur \end{bmatrix}= \\
&=\begin{bmatrix} -\frac{1}{2}\rho S_{DH}C_{DH0}V_H^2\left(1+\left|\sin(\beta)\right|\right)\cos(\beta)+\frac{1}{2}\rho S_{LH}C_{LH0}\sin(2\beta)\sin(\beta) \\ \left(-\frac{1}{2}\rho S_{DH}C_{DH0}V_H^2\left(1+\left|\sin(\beta)\right|\right)\sin(\beta)-\frac{1}{2}\rho S_{LH}C_{LH0}\sin(2\beta)\cos(\beta)\right) \\ \frac{1}{2}\rho S_{MH}L_{MH}V_H^2C_{MH}\sin(2\beta) \end{bmatrix}+\begin{bmatrix} \frac{1}{2}\rho F_{xrH}V_H^2r \\ \frac{1}{2}\rho F_{yrH}V_H^2r \\ \frac{1}{2}\rho M_{zrH}V_H^2r \end{bmatrix}+\begin{bmatrix} F_P \\ 0 \\ \varepsilon \end{bmatrix}+ \\
&+\begin{bmatrix} \left(-\frac{1}{2}\rho S_{DR}C_{DR0}V_R^2\left(1+\left|\sin(\beta_r+\delta)\right|\right)\cos(\beta_r)+\frac{1}{2}\rho S_{LR}C_{LR0}V_R^2\sin\left(2(\beta_r+\delta)\right)\sin(\beta_r)\right) \\ -\frac{1}{2}\rho S_{DR}C_{DR0}V_R^2\left(1+\left|\sin(\beta_r+\delta)\right|\right)\sin(\beta_r)-\frac{1}{2}\rho S_{LR}C_{LR0}V_R^2\sin\left(2(\beta_r+\delta)\right)\cos(\beta_r) \\ \frac{1}{2}\rho S_{MR}L_{MR}V_R^2C_{MR}\sin\left(2(\beta_r+\delta)\right) \end{bmatrix}+ \\
&+\begin{bmatrix} 0 \\ 0 \\ L_{Ry}*F_{yR}+L_{Rx}*F_{xR} \end{bmatrix}
\end{aligned}
\tag{1}
$$

Identified variables

$$A_1 = 1 + \frac{\lambda_{11}}{m_h}, \quad A_2 = 1 + \frac{\lambda_{22}}{m_h}, \quad A_3 = \frac{S_x + \lambda_{26}}{m_h}, \quad A_4 = 1 + \frac{\lambda_{66}}{I_{hzz}}, \quad A_5 = C_{DH},$$

$$A_6 = C_{LH}, \quad A_7 = C_{MH}, \quad A_8 = C_{DR}, \quad A_9 = C_{LR}, \quad A_{10} = C_{MR},$$

$$A_{11} = \frac{\rho F_{xrH}}{2m_h}, \quad A_{12} = \frac{\rho F_{yrH}}{2m_h}, \quad A_{13} = \frac{\rho F_{MrH}}{2I_{hzz}}, \quad A_{14} = \frac{F_p}{m_h}, \quad A_{15} = \frac{\varepsilon}{I_{hzz}} \quad (2)$$

List of symbols:

$m_{(\,)}$ - mass of element $(\,)$

$\lambda_{11}$ - mass of attached water masses in x direction

$\lambda_{22}$ - mass of attached water masses in y direction

$\lambda_{26}$ - static moment of attached water masses relative to xy plane

$\lambda_{66}$ - moment of inertia about z axis for attached water masses

$S_{(\,)}$ - static moment of hull relative to $(\,)$ axis

$I_{(\,)zz}$ - moment of inertia about z axis for element $(\,)$

$u$ - velocity in x direction

$v$ - velocity in y direction

$r$ - rate

$\rho$ - density of water

$V_{(\,)}$ - flow velocity for element $(\,)$

$C_{(\,)}$ - coefficient of hydrodynamic force/moment due to flow velocity

$L_{(\,)}$ - arm of force for element and load $(\,)$

$F_{()rH}$ - hydrodynamic force of hull due to rate $r$ in $(\,)$ direction

$M_{zrH}$ - hydrodynamic moment of hull due to rate $r$

$F_P$ - propeller force

$\varepsilon$ - propeller moment about z axis

$S_{(\,)}$ - area of reference for element $(\,)$

$\delta$ - rudder deflection angle

$\beta$ - angle of hull sideslip

$\beta_r$ - angle of rudder sideslip

Indexes:
$h$ - hull
H - hydrodynamic
$R$ - rudder
$x$ - in direction of x axis
$y$ - in direction of y axis
$D$ - drag
$L$ - lift
$M$ - moment
0 - base value

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