Real-time analysis of PMM tests using IIR filters – Ⅰ.

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Summary

A real-time identification algorithm is applied to analyze PMM tests. The algorithm consists of two steps. Firstly, the equations of motion for ship manoeuvrability is time-integrated in order to eliminate differentiation terms in the equation. Secondly, A CARX (Continuous Auto Regressive eXogenous) model is built using signals integrated by the IIR (Infinite Impulse Response) digital filters. The CARX model is solved in real time by the RLS (Recursive Least Square) method. By means of the procedure, the hydrodynamics derivatives can be evaluated explicitly and accumulation of integration error can be avoided. As the first report, the proposed procedure is applied to analysis of pure swaying tests and compared to the results of harmonic analysis. It is confirmed that the proposed algorithm can provide stable results under the several conditions.

Keywords：Ship handling and propulsion, IIR filter, CARX model, real-time estimation, hydrodynamic derivative.

1. Introduction

In the research field of ship manoeuvrability, PMM (Planar Motion Mechanism) tests are generally carried out to estimate the hydrodynamic derivatives. The method and the procedures are considered to be sophisticated and effective. However, the general harmonic analysis is usually applied in order to decompose the measured signal into the velocity and acceleration components. If a real-time analysis is available, efficiency of the PMM tests must be highly improved.

One of the author applied a direct parameter estimation algorithm to the simple linear response model for ship manoeuvring motion (Nomoto model)[(1),(2)]. The results showed that the direct parameter estimation algorithm with IIR (Infinite Impulse Response) filters was a powerful tool for real-time identification of ship manoeuvring indices.

In this paper, the algorithm is applied to analyses of PMM tests. Signals of the load cell and the ship movements are used for making up a CARX (Continuous Auto Regressive eXogenous) model and the coefficients of the model are transformed into the hydrodynamic derivatives. The identification algorithm is composed of the IIR digital filters and RLS (Recursive Least Square) method. The IIR digital filters are introduced to avoid numerical derivative of time history data and to reduce the influence of measurement noises. Generally, numerical derivation of the data which is contaminated by observation noises would cause decreases of accuracy and stability of the identification procedure. On the other hand, the IIR digital filters are free from the initial condition problem and the accumulation problem of integration error.

Results of the direct parameter estimation algorithm are compared with the general harmonic analysis. It is revealed that the direct parameter estimation algorithm can provide stable results under the several conditions. And, there is satisfactory agreement of the hydrodynamic derivatives estimated by the direct identification method and the harmonic analysis. Furthermore, it is clarified that the strict planar motion such as ‘pure swaying’ is not required. This concludes that the direct parameter estimation algorithm with IIR filters is a powerful tool for real-time analysis of PMM tests.

2. Equations of motions

Linearized equations of motions for ship manoeuvrability are expressed as follows with considering the external forces capturing the model ship.

$$\left.\begin{aligned} Y_{LC} &= -(m+m_y)\dot{v} + Y_v \cdot v + (Y_r - mU)\cdot r + Y_{\dot{r}} \cdot \dot{r} \\ N_{LC} &= -(I_{zz} + j_{zz})\dot{r} + N_v \cdot v + N_{\dot{v}} \cdot \dot{v} + N_r \cdot r \end{aligned}\right\} \qquad (1)$$

where $Y_v, Y_r, Y_{\dot{r}}, N_v$ $N_{\dot{v}}$ and N_r are the hydrodynamic derivatives to be estimated and Y_{LC}, N_{LC} denote the capturing forces measured by load cells.

In case of pure swaying of PMM test, the conditions of $\dot{u} = r = \dot{r} = 0$ are established. Therefore, the measured forces are expressed by the following equations,

$$\left.\begin{aligned} Y_{LC} &= -(m + m_y)\dot{v} + Y_v \cdot v \\ N_{LC} &= N_v \cdot v + N_{\dot{v}} \cdot \dot{v} \end{aligned}\right\} \tag{2}$$

3. Integral equations and CARX models

In order to avoid differentiation, equations (2) are integrated two times with respect to the time:

$$\left.\begin{aligned} Y_{LC2} &= -(m + m_y)Y_0 + Y_v \cdot Y_1 \\ N_{LC2} &= N_{\dot{v}} \cdot Y_0 + N_v \cdot Y_1 \end{aligned}\right\} \tag{3}$$

where Y_{LC2}, N_{LC2}, Y_0 and Y_1 are the double integrated values of Y_{LC}, N_{LC}, v and $\dot{v}$, respectively.

In the actual integration of equations (3), an approximate integration with the IIR digital filter is introduced. Then, equation (3) can be transformed into a CARX model as follows:

$$\varphi(t) = \Phi^T(t)\theta + e(t) \tag{4}$$

where

$$\begin{aligned} &\varphi(t) = Y_{LC2}(t) \quad or \quad N_{LC2}(t) \\ &\Phi^T(t) = \{Y_0(t), Y_1(t)\} \\ &\theta^T = \{-(m + m_y), Y_v\} \quad or \quad \{N_{\dot{v}}, N_v\} \end{aligned} \tag{5}$$

and $e(t)$ denotes the white noise that was introduced for stochastic treatments.

The fitting problem of CARX models are carried out at very high speed, almost the same as real-time, by the RLS method[3].

4. Real-time estimation of hydrodynamic derivatives

Figure 1 shows the screenshot of the software based on the proposed method. The left side of the screen shows movement of the model and its trajectory. In the upper three graphs in the right side of the screen, time histories of swaying motion, lateral force and yaw moment are indicated. In the graphs, the original signals and the IIR filtered signals are indicated by green and blue colored lines, respectively. In the lower two graphs in the right part, identified hydrodynamic derivatives are plotted and the convergence of the values can be seen.

Table 1 shows the comparisons of the hydrodynamic derivatives (non-dimensional) identified by the proposed method and harmonic analysis. The values of the proposed method are the instantaneous values indicated in Figure 1. Looking at the table, however, good agreement can be seen. Therefore, it can be concluded that the proposed method has good accuracy and is a powerful tool of real-time estimation of hydrodynamic derivatives.

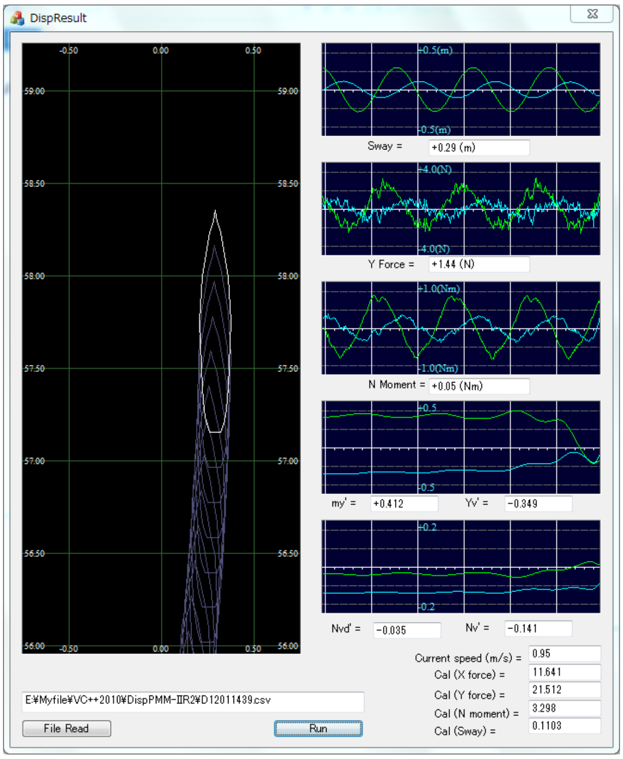

Figure 1 Screenshot of the real-time estimation of hydrodynamic derivatives.

Table 1 Comparison of the hydrodynamic derivatives.

Derivatives	Proposed method	Harmonic analysis
m_y'	0.412	0.424
Y_v'	-0.349	-0.366
N_v'	-0.141	-0.143
$N_{\dot{v}}'$	-0.035	-0.037

References

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