Computer-mathematical modeling of board oscillations of a military marine vessel based on the degenerate optimal singular adaptive M3A1 computer observer– Part I

Lyubomir Sotirov, Nikola Lyutov, Todor Kolarov, Stela Sotirova

Abstract: *The paper presents a new approach of discrete adaptive computer observation and modeling of board oscillations of military marine vessels considered to be linear and non-stationary discrete processes so far. The tools of the Theory of optimal singular adaptive computer observation and discrete modeling, which has been developed in the recent 25 years, are applied.*

Keywords: *Discrete systems, degenerate optimal singular adaptive computer observation, identification, discrete modeling, estimation of the initial state vector, board oscillations , military marine vessels, Matlab implementation.*

1. Introduction

The problems, related to the estimation of the varying influence of marine environment on floating semi-submerged vessels [1,2], as well as on their behaviour during exploitation, are of significant interest /e.g. under circumstances of military marine study practices, battles or guard service/.

This stimulates interest to the computer - mathematical modeling of these problems on the basis of input-output data, which objective is to establish the cause-and-effect relation between the marine motion and the thereof arising oscillations of the marine vessel which might be traced in the chain: oscillations – dynamics – kinematics.

Obviously, the obtained results might as well be used for optimization of the dynamic behaviour of the military marine vessel both in normal and extreme conditions.

In the conditions of the experiment, organized in the respective way, marine motion can be simulated as a superposition of constant influences, differing in quantity, sign and displaced in time.

The second stage in the formulated classical problem can be solved by means of the modern toolbox of the computer- mathematical Theory of optimal singular adaptive observation of dynamic processes [4-17]. As a result, after structural identification and using an original method, the unknown vector parameters of discrete mathematical models and their initial and current states can be determined.

The third stage (kinematics) consists in interpretation only of the established motions of the discrete models of military marine vessels.

Certain assumptions and approximations are made in determining the concrete classical mathematical models of floating objects, which are rather different in shape and application, and parameters and phenomena which are considered insignificant or hard to measure are ignored. Therefore, sometimes the developed models do not correspond adequately to the respective marine objects structurally and/or parametrically. Moreover, the floating objects might change both their structure and real-time parameters as a result from different conditions of sailing and exploitation regime (depending on the cargo, its disposition etc.), which we illustrate below.

In the present paper the presented methodology is applied in the concrete case of simulated board oscillations of a military marine vessel model.

2 Description of the modeled military marine object and the carried out test

A model of a military marine object which weight is Δ=16.8 [kg], length L=1.17 [m], width B=0.27 [m] and depth of submerging of vessel T=0.077 [m].

The oscillations of the examined model around its longitudinal axis in hanging position out of water environment are determined by special apparatus located in "Ship Theory" laboratory at Technical University – Varna. The deviation of the nib of the double coordinate registering tool from the neutral, zero position in [mm] is taken as an output variable. Afterwards, the data are discretised with a constant step of discreteness which is equal to 0.1 [s].

Only a part of the taken input-output data is presented below for the case when the model of a marine vessel is taken out of equilibrium state and oscillated by an input influence, which is placing and taking of weights of 0.1 [kg] and 0.2 [kg] from the board.

k		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
u(k)	[kg]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
y(k)	[mm]	0	2	6	13	20	22	16	7	-4	-11	-13	-6	11	25	34

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
34	25	13.5	-3	-11	-13	-6.5	10	23	29	23	12	0	-7	-10	-7	5	14.5

The automated performance of hydrodynamic tests of ship models and the application of certain mathematical statistics methods for increasing the accuracy and truthfulness of measurements are investigated in [3].

3. Discrete modeling of the dynamics of the military marine vessel

The approach requires presentation of the discrete linearized observable submodels of the studied board oscillations process in the state space as follows:

$$\mathbf{x}(k+1)=\mathbf{A}\mathbf{x}(k)+\mathbf{b}u(k), \quad \mathbf{x}(0)=\mathbf{x_0}, \tag{1}$$

$$y(k)=\mathbf{c}^T\mathbf{x}(k), \quad k=0,1,2,...., \tag{2}$$

where $\mathbf{x}(k)\in R^n$ is an unknown current state vector, $\mathbf{x}(0)\in R^n$ is an unknown initial state vector, $u(k)\in R^1$ is a control scalar input, $y(k)\in R^1$ is the measured scalar output reaction of the discrete model. A is an unknown matrix of the type:

$$\mathbf{A}=\begin{bmatrix} \mathbf{0} & | & \mathbf{I_{n\text{-}1}} \\ ... & ... & ... \\ & \mathbf{a}^T & \end{bmatrix}, \tag{3}$$

$$\mathbf{a}^T=[a_1, a_2, ..., a_n], \tag{4}$$

where $\mathbf{I_{n\text{-}1}}$ is a single (n-1)x(n-1) matrix,

$$\mathbf{b}^T=[0, ...0, 1], \tag{5}$$

$$\mathbf{c}^T=[1, 0, ..., 0]. \tag{6}$$

The following difference equation 'input- output' corresponds to the computer-mathematical model (1-6):

$$y(k+n)-a_n y(k+n-1)-a_{n-1}y(k+n-2)- \dots - a_2 y(k+1)- a_1 y(k)=u(k),$$
$$k=0,1,2,... \qquad (7)$$
$$y(0)=y_0,\ y(1)=y_1,\ \dots\ y(n-1)=y_{n-1}.$$

So does the following transfer function

$$\mathbf{W}(z)=\frac{\mathbf{Y}(z)}{\mathbf{U}(z)}=\frac{1}{z^n-a_n z^{n-1}-\dots-a_2 z-a_1}. \qquad (8)$$

4. Algorithmic synthesis of the degenerate optimal singular adaptive M3A1 computer observer

Step 1. Formation of input-output data arrays:

$$\mathbf{Y}_1^{\mathrm{T}}=[y(0),y(1),...,y(n-1)],$$
$$\mathbf{Y}_2^{\mathrm{T}}=[y(n),y(n+1),...,y(2n-1)],$$
$$\mathbf{V}^{\mathrm{T}}=[u(0),u(1),...,u(n-1)],$$

$$\mathbf{Y}_{12}=\begin{bmatrix} y(0) & y(1) & . & . & y(n-1) \\ y(1) & y(2) & . & . & y(n) \\ y(2) & y(3) & . & . & y(n+1) \\ . & . & & & . \\ y(n-1) & y(n) & . & . & y(2n-2) \end{bmatrix},$$

where $\mathbf{Y}_{12}$ is a n x n Hankel matrix.

Step 2. Calculation of the assessments of the n-dimensional vector **a**, as a solution of the system of linear algebraic equations:

$$\mathbf{Y}_{12}\hat{\mathbf{a}}=\mathbf{Y}_2-\mathbf{V}.$$

Step 3. Calculation of the elements of the n-dimensional vector **x**(0), with the help of the optimal computer estimator of the type:

$$\hat{\mathbf{x}}(0)=\mathbf{Y}_1.$$

Step 4. Assessment of the n–dimensional current state vector **x**(k), k=1,2,.., with the help of the full optimal singular adaptive computer observer of the type:

$$\hat{\mathbf{x}}(k+1)=\hat{\mathbf{F}}\hat{\mathbf{x}}(k)+\mathbf{b}u(k)+\mathbf{g}\mathbf{y}(k),\quad \hat{\mathbf{x}}(0)=\hat{\mathbf{x}}_0,$$
k=0,1,2,….,

where:

$$\hat{\mathbf{F}} = \hat{\mathbf{A}} - \mathbf{g}\mathbf{c}^{\mathrm{T}},$$
$$\mathbf{g}^{\mathrm{T}} = [g_1, g_2, ... g_n].$$

The choice of vector **g** elements is arbitrary and can be effected by one of the following ways:

1) **g**=**b**.
2) **g**=0.
3) The vector **g** elements could be selected so that the $\hat{\mathbf{F}}$ matrix possesses eigenvalues located inside the unit circle.

Step 5 . The degenerate OSA computer observer (at **g**=0) of the type:

$$\hat{\mathbf{x}}(k+1) = \hat{\mathbf{A}}\hat{\mathbf{x}}(k) + \mathbf{b}u(k), \;\; \hat{\mathbf{x}}(0) = \hat{\mathbf{x}}_0,$$
k=0,1,2,….,

could be considered as a degenerate case of the full OSA computer observers (at **g**=0) and can be constructed easier.

It follows from the analysis of the derived algorithm:

M3A1 Theorem. An only solution of the formulated task for optimal singular adaptive computer observation and modeling with the help of M3A1 algorithm, exists if and only if the matrix $\mathbf{Y}_{12}$ is not singular or:

$$\det(\mathbf{Y}_{12}) \neq 0 . \qquad (9)$$

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ABOUT THE AUTHORS

Prof., DSc. Lyubomir Nikolaev Sotirov
Stela Lyubomirova Sotirova, bachelor of computer science, Varna Technical University, Bulgaria, tel. 052-30-06-96, Faculty of Computer Science and Automation,
E- mail: Sotirov@ieee.bg, stellasot@hotmail.com
Prof., Dr. Nikola Rashkov Lyutov, Varna Free University, Bulgaria, tel. 052 602 708……
Department of Informatics, E- mail: Lyutov@vfu.bg
Assoc. prof. Todor Petrov Kolarov, Varna Technical University, Bulgaria, tel. 052-30-78-97
Faculty of Shipbuilding, E- mail: todor_p_kolarov@yahoo.com