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A Technique of Parameter Identification via Mean Value and Variance and Its Application to Course Changes of a Ship

Fuyuki HANE* ,and Isao MASUZAWA**

Marketing & RD Center, Tokimec Inc., Nasumachi, Tochigi, 325-0001, JAPAN
Tel:+81-287-64-0936; Fax:+81-287-63-3778
E-mail:*f-hane@tokimec.co.jp, **i-masuzawa@tokimec.co.jp

Abstract

The technique is reported of identifying parameters in off-line process. The technique demands that closed-loop system consists of a reference and two-degree-of-freedom controllers (TDFC) in real process. A model process is the same as the real process except their parameters. Deviations are differences between the reference and the output of the plant or the model. The technique is based on minimizing identification error between the two deviations. The parameter differences between the plant and the model are characterized of mean value and of variance which are derived from the identification error. Consequently, the algorithm which identifies the unknown plant parameters is shown by minimizing the mean value and the variance, respectively, within double convergence loops.

The technique is applied to course change of a ship. The plant deviation at the first trial is shown to occur in replacing the nominal parameters by the default parameters. The plant deviation at the second trial is shown to not occur in replacing the nominal parameters by the identified parameters. Hence, the identification technique is confirmed to be feasible in the real field.

1 Introduction

The automatic heading control system of a ship namely, *autopilot* occupies a important part of marine equipments. When designing the controller of the autopilot, we confront problem that the ship parameters are unknown. The parameters furthermore depend strongly on load condition which varies draught. Many control methods reported in [1] have been suggested and realized to solve the problem. They have adopted techniques based on on-line operation. This time, we report new technique that identifies the parameters in off-line process. Performance of the autopilot will improve by the identified ship parameters. It however has limitation that the plant model is equivalent to first-order system.

We show that the plant parameters can identify by mean value and variance of the identification error namely, the difference between the plant deviation and the model deviation. By separating the identification process from real process, the principle is simplified and is guaranteed with the stability. This technique might be similar to Least Square Method in view of taking the variance (accumulation which takes a square) of the identification error, It however has features of not only minimizing the variance but also minimizing the mean value (fixed value).

The time response solution of the model deviation adopts not numerical integration solution but inverse Laplace transform solution in this technique. The transform solution is of great advantage to shortening much calculation time which takes place because of double convergence loops. Non-linear term like a relay type steering machine isn't considered, as a result, in model. By the way, to make the output of the plant that coincides with the reference, we use system [2] which consists of the reference and TDFC.

2 Identification Technique

2.1 Construction

The construction of the identification technique is shown in Fig.1. There are the real process and the off-line process. The reference and the TDFC are the same in their process. The feedforward controller sets the inverse plant with the nominal parameters. The model is the same as the plant except its parameters. Thus, their deviations occur in the case that the nominal parameters differ from the plant parameters or the model ones. The parameter adjuster makes the identification error minimize by changing the model parameters.

Fig.2 shows the real process in detail. It is derived from closed loop of changing course. The plant consists of a ship and a gyrocompass excluding a steering machine. The ship is expressed with a first-order system. The gyrocompass is expressed with an integrator. Then the transfer function from the reference and the disturbance to the deviation gives

$$E_a(s) = \frac{K_{sa}[(U_{\frac{T}{K}a}s^2 + U_{\frac{1}{K}a}s)R(s) - (T_{rn}s+1)D_a(s)]}{B_a(s)} \quad (1)$$

$$U_{\frac{T}{K}a} = \frac{T_{sa}}{K_{sa}} - \frac{T_{sn}}{K_{sn}} \quad (2)$$

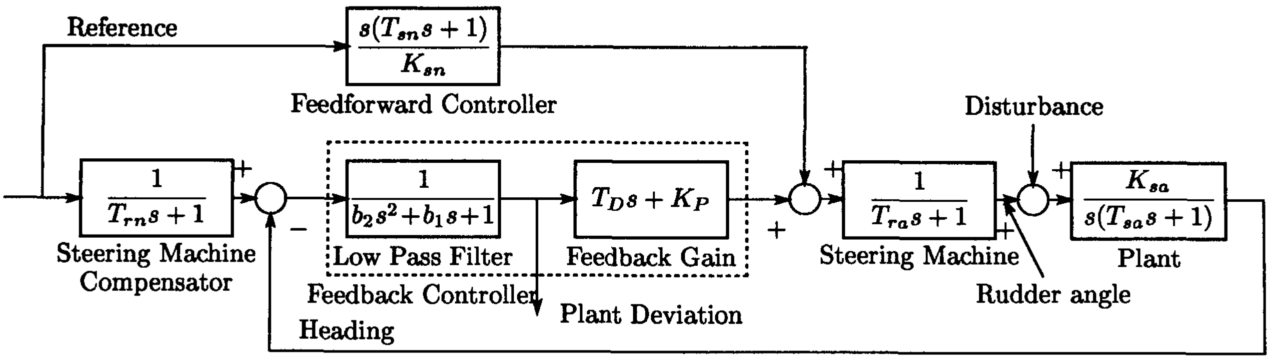

Fig. 2: Real Process in detail

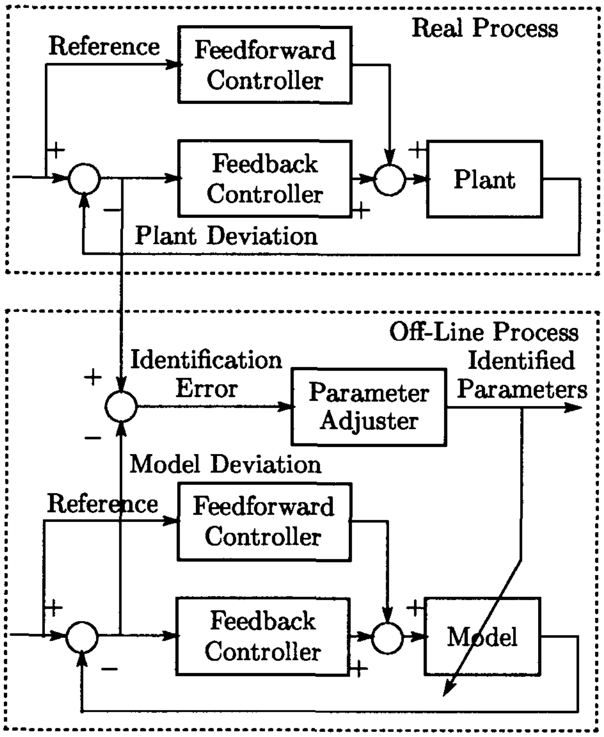

Fig. 1: Construction of Identification Technique

$$U_{\frac{1}{K}a} = \frac{1}{K_{sa}} - \frac{1}{K_{sn}} \tag{3}$$

$$B_a(s) = C_{TC}(s)(T_{sa}s + 1) + K_{sa}C_{FB}(s) \tag{4}$$

$$C_{TC}(s) = s(T_{rn}s + 1)(b_2s^2 + b_1s + 1) \tag{5}$$

$$C_{FB}(s) = T_Ds + K_P \tag{6}$$

where, E is the deviation, R is the reference, D is the disturbance, K_s, T_s are a gain and a time constant of the ship parameters, respectively, suffix $_a$, $_n$ mean actual and nominal, respectively, T_r is a time constant of the steering machine, T_D, K_P are a derivative gain and a proportional gain of the feedback gain, respectively, b_2, b_1 both are time constants of the low pass filter, and s is the symbol of the Laplace operator, $U_{\frac{T}{K}}$, $U_{\frac{T}{K}}$, B, C_{TC} and C_{FB} are variables. We assume that poles of $B_a(s) = 0$ are all negative and $T_{ra} = T_{rn}$.

We define the disturbance as a off-set which varies after changing course. In addition, the disturbance's magnitude and time-series depend on the reference characteristics. Consequently the disturbance yields

$$D_a(s) = \frac{d(0)_a}{T_{rn}s + 1}\frac{R(s)}{r_\Sigma} \tag{7}$$

where, $d(0)$ is the off-set, r_Σ is a amount of the reference.

2.2 Principle

After the identification error defines what subtracts the model deviation from the plant deviation, their deviations are replaced by Eq.(1). Thus, the identification error Γ is expressed in the form

$$\Gamma(s) = E_a(s) - E_m(s) \tag{8}$$

$$= U_{\frac{T}{K}}F(s) + U_{\frac{1}{K}}G(s) \tag{9}$$

$$U_{\frac{T}{K}} = \frac{T_{sa}}{K_{sa}} - \frac{T_{sm}}{K_{sm}} \tag{10}$$

$$U_{\frac{1}{K}} = \frac{1}{K_{sa}} - \frac{1}{K_{sm}} \tag{11}$$

$$F(s) = sC(s)R(s) \tag{12}$$

$$G(s) = C(s)R(s) \tag{13}$$

$$C(s) = \frac{B_n(s)s + K_{sn}C_{TC}(s)d(0)_m/r_\Sigma}{B_a(s)B_m(s)}\frac{K_{sa}K_{sm}}{K_{sn}} \tag{14}$$

$$B_n(s) = C_{TC}(s)(T_{sn}s + 1) + K_{sn}C_{FB}(s) \tag{15}$$

$$B_m(s) = C_{TC}(s)(T_{sm}s + 1) + K_{sm}C_{FB}(s) \tag{16}$$

where, suffix $_m$ mean model, F, G are variables. We assume that poles of $B_n(s) = 0$ and $B_m(s) = 0$ are all negative, $d(0)_a$=$d(0)_m$.

The identification error has two isolated parameter difference coefficients in Eq.(9). And we can treat the time series data of the deviation by inverting the identification error Eq.(8). Thereby, the error can evaluate through statistical operations. The mean value and the variance against the error in the time domain are expressed in the form

$$\gamma(t) = e_a(t) - e_m(t) \tag{17}$$

$$M_\gamma = U_{\frac{T}{K}}M_f + U_{\frac{1}{K}}M_g \tag{18}$$

$$V_\gamma = U_{\frac{T}{K}}^2V_f + 2U_{\frac{T}{K}}U_{\frac{1}{K}}V_{\sqrt{fg}} + U_{\frac{1}{K}}^2V_g \tag{19}$$

where, t is time, $\gamma(t) = \mathcal{L}^{-1}[\Gamma(s)]$, $e(t) = \mathcal{L}^{-1}[E(s)]$, $f(t) = \mathcal{L}^{-1}[F(s)]$ and $g(t) = \mathcal{L}^{-1}[G(s)]$, $\mathcal{L}$ is the symbol of the Laplace transform, $M_{(\cdot)}$, $V_{(\cdot)}$ stand for mean value and variance, respectively, and n is sample size,

$$M_{(\cdot)} = \sum_{i=1}^{n} (\cdot)_i / n, \quad V_{(\cdot)} = \sum_{i=1}^{n} ((\cdot)_i - M_{(\cdot)})^2 / n$$

Hence, by finding from Eqs.(18) and (19) the mean value and the variance are characterized as follows:

- Variance

$$V_\gamma = \begin{cases} +, \text{downward convex shaped} \\ \qquad\qquad \forall T_{sm}, \exists K_{sm} \\ \text{Minimum value} \quad \text{at} \dfrac{T_{sm}}{K_{sm}} = \dfrac{T_{sa}}{K_{sa}} \\ \approx U^2_{\frac{1}{K}} V_g \end{cases} \tag{20}$$

  Thus, the T_{sm}/K_{sm} ratio term coincides with the T_{sa}/K_{sa} ratio term by minimizing the variance.

- Mean Value-1 under minimizing the variance

$$M_\gamma = \begin{cases} +, - \qquad \forall K_{sm} \\ \text{Minimum value} \quad \text{at} \dfrac{1}{K_{sm}} = \dfrac{1}{K_{sa}} \\ \approx 0 \end{cases} \tag{21}$$

  Thus, the $1/K_{sm}$ term coincides with the $1/K_{sa}$ term by minimizing the absolute mean value.

- Mean Value-2 under minimizing the variance

$$\frac{dM_\gamma}{dK_{sm}} = \begin{cases} + & \text{if } r_\Sigma > 0 \\ - & \text{if } r_\Sigma < 0 \end{cases} \tag{22}$$

2.3 Procedure

The procedure shows in Fig.3. We store the deviation of the real process as the time series data, set the coefficients of the reference and the TDFC in the off-line process. The procedure consists of the two convergence loops: one is that the variance V_γ gets minimized by adjusting the parameter T_{sm}, the other is that the absolute mean value $|M_\gamma|$ gets minimized by adjusting the parameter K_{sm}. The convergence method uses Golden Section Method. Hence, the model parameters K_{sm} and T_{sm} converge on the unknown plant parameters K_{sa} and T_{sa}.

We continuously show how to calculate $e_m(t)$. The equation of the model deviation is obtained by modifying Eqs(1) and (7) as follows

$$E_m(s) = \frac{(U_{\frac{T}{K}m} s^2 + U_{\frac{1}{K}m} s + d(0)_m / r_\Sigma) \times K_{sm} R(s) + I(s)}{B_m(s)} \tag{23}$$

where, $I(s)$ is fourth-order initial condition and is used in the case of $R(s)$ mode varying. $R(s)$ gives

$$R(s) = \frac{R_5}{s^5} + \frac{R_4}{s^4} + \frac{R_3}{s^3} + \frac{R_2}{s^2} + \frac{R_1}{s} \tag{24}$$

where, the coefficients $R_{i,i=1,5}$ are shown in Table 1. In Table 1, *Ac*, *Ve*, *De* and *Se* mean mode; acceleration, velocity, deceleration and settlement, respectively, $\beta_{(\cdot)}$ are constants, $r_{(\cdot)}$ are amounts of the

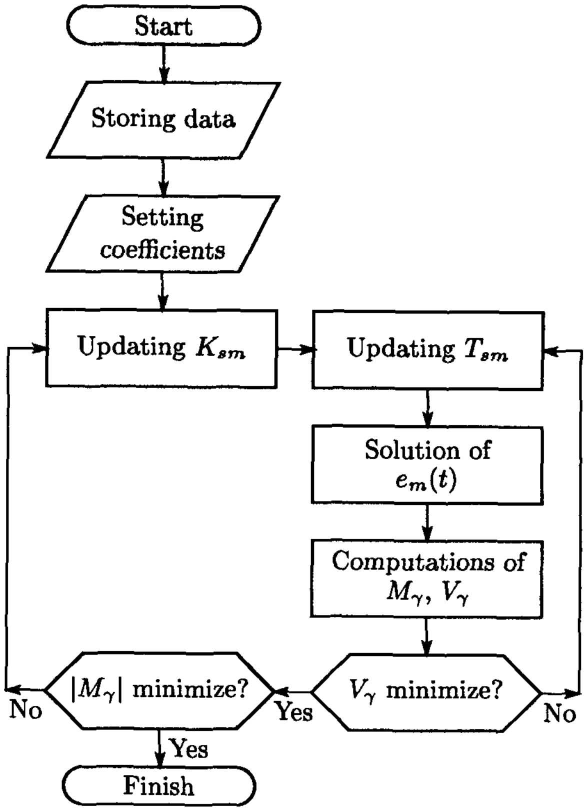

Fig. 3: Procedure Flow

Table 1: Coefficients of Reference

Mode	R_1	R_2	R_3	R_4	R_5
Ac	0	C_{2ac}	C_{1ac}	$\dfrac{\beta_{ac}}{T_{ac}}$	$\dfrac{-2\alpha_{ac}}{T^2_{ac}}$
Ve	r_{ac}	ω_r	0	0	0
De	$r_{ac}+r_{ve}$	ω_r	0	$\dfrac{\beta_{de}}{T_{de}}$	$-2\dfrac{\beta_{de}}{T^2_{de}}$
Se	r_Σ	0	0	0	0

where, $\alpha_{ac} = C_{1ac} + \beta_{ac}$, $r_\Sigma = r_{ac} + r_{ve} + r_{de}$, $T_\Sigma = T_{ac} + T_{ve} + T_{de}$.

Table 2: Combination of Poles

Damping ratio	$\zeta_1 < 1$	$\zeta_1 = 1$	$\zeta_1 > 1$
$\zeta_2 < 1$	O	O	O
$\zeta_2 = 1$	O	—	—
$\zeta_2 > 1$	O	—	O

reference, $T_{(\cdot)}$ are time, C_{1ac}, C_{2ac} are the plant's angular acceleration and angular velocity, respectively, ω_r is the reference's angular velocity.

The fifth-order characteristic equation, *i.e.* $B_m(s)$ =0 can be factored in the form

$$(s+p)(s^2 + 2\zeta_1\omega_{n1}s + \omega^2_{n1})(s^2 + 2\zeta_2\omega_{n2}s + \omega^2_{n2}) = 0 \tag{25}$$

where, p is a real pole, $\zeta_{1,2}$ are damping ratio, $\omega_{1,2}$ are natural frequency [rad/s].

The combination of the poles in Eq.(25) shows in

Table 3: Experimental Conditions

Date	December 23, 1996
Weather	Fine, breeze
Area	The Enshu Nada of Japan
Ship	Lime-stone Carrier, length140[m]
Load/Speed	Ballast condition/≈10 [kt]
r_Σ, ω_r	20 [deg], 0.3 [deg/s]

Table 4: Coefficients of Controllers

	First Trial	Second Trial
K_{sn} [1/s], T_{sn} [s]	0.059, 32.2	0.034, 11.4
K_P, T_D [s]	0.68, 23.75	3.33, 40.64
b_2 [s^2], b_1 [s]	25.6, 11.7	3.3, 4.1
r_{ac} [deg], T_{ac} [s]	3.4, 22.2	2.7, 16.6
r_{ve} [deg], T_{ve} [s]	13.6, 44.7	14.7, 49.2
r_{de} [deg], T_{de} [s]	3.4, 22.3	2.6, 17.3
$\beta_{ac,de}$ [deg/s^2]	0.081, -0.082	0.100, -0.104
C_{1ac} [deg/s^2]	0	0
C_{2ac} [deg/s]	0	0.02
$d(0)_m$ [deg]	-0.26	-0.30

Table 2. We assume that there is no other combination but Table 2. Thus, the solution of the model deviation is based on Eq.(25) at inverting Eq.(23) from s domain to time domain.

The model off-set $d(0)_m$ is calculated from the heading ψ in the settlement state, *i.e.* $d(0)_m = \Sigma_{i=1}^{n\_se} \psi_i / n\_se / K_P$, n_se is sample size.

3 Experimental Results

We apply the proposed identification technique to changing course of a ship. After verifying the technique by simulations, we experimented on the conditions shown in Table 3.

The Conditions of the procedure are as follows: The deviation data are time series which divide time boundary $[1.7T_{de}, T_\Sigma + 0.8T_{de}]$[s] by $n = 10$. The searching ranges of the model parameters K_{sm} and T_{sm} are [0.02, 0.1][1/s] and [5, 100][s], respectively. Constants of the feedback controller refer to prescribed tables given K_{sm} and T_{sm}.

The trial results show in Table 4, Figs.4 and 5. The plant deviation in Fig.4 occurs to use the default values as the nominal parameters in the first trial. The nominal parameters of the second trial are identified by the plant deviation of the first trial. The plant deviation in Fig.5 hardly occur. Thus, we confirm the identified parameters are similar to the actual parameters. From the rudder angle traces the practical steering machine is the nonlinear on-off relay type. Nevertheless the technique can perform enough.

4 Conclusions

We suggest the one-input identification technique in off-line process. We express that the plant parameters can identify from the plant deviation: The characteristics of the mean value and of the variance derive from the identification error. Minimizing the mean value and the variance coincides with identifying the plant parameters. In addition, we show the identification technique is effective through the experimental results. The technique also uses the realistic reference but not the special identification-oriented reference. Consequently, the feasibility promises highly in actual field.

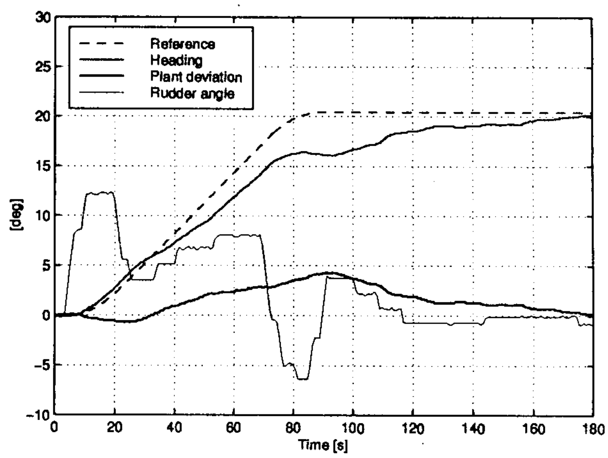

Fig. 4: First Trial

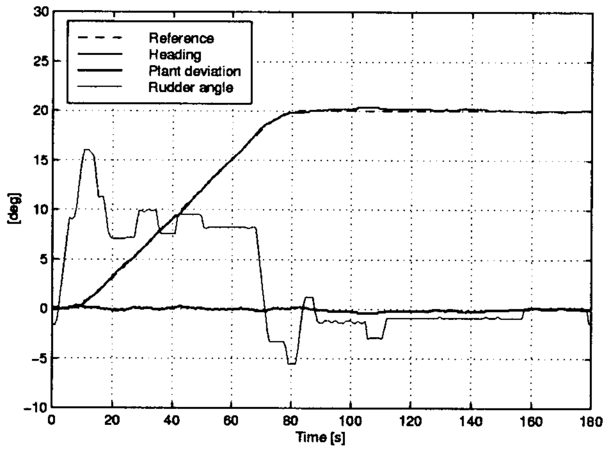

Fig. 5: Second Trial

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