OPTIMIZATION WITH JACOBIAN APPROACH FOR DIVING MOTION OF ROV SYSTEM

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ABSTRACT

Indonesia is a country with a large watery area of about two thirds of the country's total territory. Therefore, the country requires a multifunctional vehicle that can be utilized for a mitigation in river and a maritime defense system. One of the multifunctional vehicles is the Remote Operated Vehicle (ROV). In this paper the optimization of ROV system with Jacobian approach for ROV system is studied. With jacobian approach, linearization of nonlinear ROV system to analyze controllabity and observability without control system could be accomplished. Linear system for diving motion of ROV has a 3 DOF model, which are surge, heave, and pitch. Results of the optimization with Jacobian approach show that the ROV system is controllable and observable.

Keywords: *AUV, optimization, Jacobian, linear system, controllable, observable*

1. INTRODUCTION

More than 70% of Indonesian teritory comprises of seas, so it has a great potency which need to be looked after. Advanced technology is required to aid in managing the potential resources at sea. Remote Operated Vehicle (ROV) is one of the advanced technology necessary in this case, in particular to assist variours activities of underwater exploration in the deepsea. ROV is very useful for ocean observation since it require a tethered cable, and it can swim freely without restriction [1]. ROV can be used for underwater exploration, mapping, underwater defense system equipment, sensor off board submarines, inspection of underwater structures and natural resources, observing condition of the earth surface plates, and so on.

One important aspect that should be established in the design of ROV is the clarification on its observability and controllability, based on a mathematical model [2]. The mathematical model contains various hydrodynamic force and moment expressed collectively in terms of hydrodynamic coefficients [3]. ROV nonlinear system causes many uncertainties in the modeling, so requires linearization to obtain more viable results.

This paper presents a study to solve problems in optimization utilizing the Jacobian approach for ROV system. Optimization of ROV system is considered as the foundation with regards to navigation, control and guidance system in ROV.This study emphasized on basic development control, navigation and guidance of ROV.

2. REMOTED OPERATED VEHICLE (ROV) MODEL

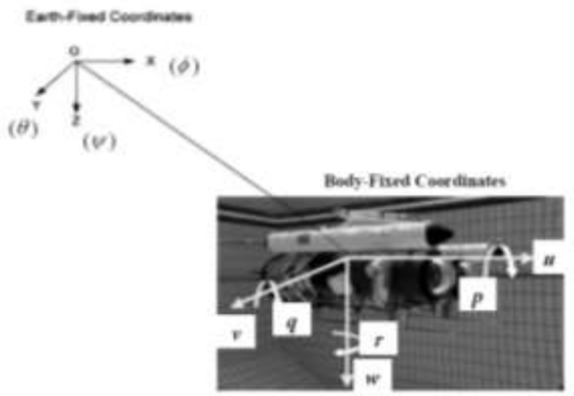

Figure 1. 6 DOF in ROV motions [7]

Two important things need to be first recognized on the Remote Operated Vehicle (ROV), that is the Earth Fixed Frame (EFF) and the Body Fixed Frame (BFF) [4]. EFF is used to describe the position and orientation of the ROV with the position of the x-axis direct to the north, the *y*-axis to the east and the *z*-axis toward the center of the earth.While BFF is used to describe the speed and acceleration of the ROV with the starting point at the center of gravity, *x*-axis direct to the ship bow, positive *y*-axis direct to the right hand side of the ship and positive *z*-axis direct downward [5,6].

As shown in Figure 1 and Table 1, an AUV or ROV has 6 DOF mode of motions, where 3 DOF for translational motion and 3 DOF for rotational motion in with regards tox, y and z axis. In the dynamics problem, motion of the ROV is influenced byexternal forcesas follows [8]:

$$\tau = \tau_{hidrostatis} + \tau_{addedmass} + \tau_{drag} + \tau_{lift} + \tau_{control}$$

Table 1. Notation of ROV Motion Axis [4,8]

DOF	Translational And Rotational	Force / Moment	Linear and Anguler Velocity	Potition /Angle Euler
1	Surge	*X*	*U*	*x*
2	Sway	*Y*	*V*	*y*
3	Heave	*Z*	*W*	*z*
4	Roll	*K*	*P*	ϕ
5	Pitch	*M*	*Q*	*θ*
6	Yaw	*N*	*R*	Ψ

General equation of ROV motions in 6 DOF consists of 3 first equation for translational motion and 3 second equation for rotational motions, as described in the following.

$$\eta = [\eta_1^T, \eta_2^T]^T, \quad \eta_1 = [x, y, z]^T, \quad \eta_2 = [\emptyset, \theta, \Psi]^T;$$

$$v = [v_1^T, v_2^T]^T, \quad v_1 = [u, v, w]^T, \quad v_2 = [p, q, r]^T;$$

$$\tau = [\tau_1^T, \tau_2^T]^T, \quad \tau_1 = [X, Y, Z]^T, \quad \tau_2 = [K, M, N]^T;$$

Where ***η*** vector is the position and orientation of the EFF, ***v*** vector velocity of linear and angular of the BFF, the position and orientation of the BFF, and τ description of force and moment in ROV of the BFF.

By combining equations hydrostatic force, lift added mass, drag, thrust and assuming a diagonal tensor of inertia (*I_o*) is zero then the total forces and moments of models obtained from the following [4,9]. This paper is using equation of motion in the form of three Degree of Freedom (3-DOF), those are surge, heave and pitch. General equation of motion in 3-DOF ROV consists of surge, heave and pitch motion as follows:

Surge : $\dot{u} = \frac{X_{res}+X_{|u|u}u|u|++X_{wq}wq+X_{qq}qq+X_{prop}-m[wq-x_G(q^2)+z_G(\dot{q})]}{m-X_{\dot{u}}}$

Heave :

$$\dot{w} = \frac{Z_{res} + Z_{|w|w}w|w| + Z_{q|q|}q|q| + Z_{\dot{q}}\dot{q} + Z_{uq}uq + Z_{uw}uw + Z_{uu\delta_s}u^2\delta_s - m[-uq - z_G(q^2) + x_G(-\dot{q})]}{m - Z_{\dot{w}}}$$

Pitch:

$$\dot{q} = \frac{M_{res} + M_{w|w|}w|w| + M_{q|q|}q|q| + M_{\dot{w}}\dot{w} + M_{uq}uq + M_{uw}uw + M_{uu\delta_s}u^2\delta_s - (m[z_G(\dot{u} + wq) - x_G(\dot{w} - uq)])}{I_y - M_{\dot{q}}}$$

This type of ROV, shown in Table 2, using only single propeller on the tail ROV which will produces x_{prop} and additional moments K_{prop}. External forces and moments acting on the ROV are the hydrostatic force, thrust and hydrodynamic force and where every object in the water will have a hydrostatic force consisting of gravity and buoyancy forces. While hydrodynamic component consists of added mass, drag and lift. Thrust use fin to control the balance of the ship which require a constant rate. ROV specifications include, among others, weight of 20 kg, length of 2 m, and a diameter of 30 cm

In this paper the nonlinear system of ROV model can be linearized with Jacobian approach where the nonlinear ROV system in general as follows :

$$\dot{x}(t) = f(x(t), u(t), t)$$
$$y(t) = g(x(t), u(t), t) \qquad (9)$$

Sothe Jacobian matrix is formed as follows [2]:

$$\frac{\partial f(\bar{x},\bar{u},t)}{\partial x} = \begin{bmatrix} \frac{\partial f_1(\bar{x},\bar{u},t)}{\partial x_1} & \frac{\partial f_1(\bar{x},\bar{u},t)}{\partial x_2} & \cdots & \frac{\partial f_1(\bar{x},\bar{u},t)}{\partial x_n} \\ \frac{\partial f_2(\bar{x},\bar{u},t)}{\partial x_1} & \frac{\partial f_2(\bar{x},\bar{u},t)}{\partial x_2} & \cdots & \frac{\partial f_2(\bar{x},\bar{u},t)}{\partial x_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_n(\bar{x},\bar{u},t)}{\partial x_1} & \frac{\partial f_n(\bar{x},\bar{u},t)}{\partial x_2} & \cdots & \frac{\partial f_n(\bar{x},\bar{u},t)}{\partial x_n} \end{bmatrix} \qquad (10)$$

So equation 3 - 8 can be expressed as follows:

$$\begin{bmatrix} m - X_{\dot{u}} & 0 & mz_G \\ 0 & m - Z_{\dot{w}} & mx_G + Z_{\dot{q}} \\ mz_G & mx_G - M_{\dot{w}} & I_y - M_{\dot{q}} \end{bmatrix} \begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \end{bmatrix}$$

$$= \begin{bmatrix} X_{res} + X_{|u|u} u|u| + + X_{wq} wq + X_{qq} qq + X_{prop} - m[wq - x_G(q^2)] \\ Z_{res} + Z_{|w|w} w|w| + Z_{q|q|} q|q| + Z_{uq} uq + Z_{uw} uw + Z_{uu\delta_s} u^2 \delta_s - m[-uq - z_G(q^2)] \\ M_{res} + M_{w|w|} w|w| + M_{q|q|} q|q| + M_{uq} uq + M_{uw} uw + M_{uu\delta_s} u^2 \delta_s - (m[z_G(wq) - x_G(-uq)]) \end{bmatrix}$$

Furthermore linear system is obtained as follows :

$$\dot{x}(t) = A\, x(t) + Bu(t)$$
$$y(t) = Cx(t) + Du(t) \qquad (17)$$

$$A = \begin{bmatrix} \frac{Z_1}{Z} & \frac{Z_2}{Z} & \frac{Z_3}{Z} \\ \frac{Z_4}{Z} & \frac{Z_5}{Z} & \frac{Z_6}{Z} \\ \frac{Z_3}{Z} & \frac{Z_7}{Z} & \frac{Z_8}{Z} \end{bmatrix} \begin{bmatrix} 2uX_{|u|u} & q(X_{wq} - m) & 2qX_{qq} + wX_{wq} - mw + 2qmx_G \\ qZ_{uq} & 2wZ_{|w|w} + uZ_{uw} & 2qZ_{q|q|} + uZ_{uq} + mu + 2qmz_G \\ qM_{uq} + wM_{uw} + 2uM_{uu\delta_s}\delta_s & 2wM_{w|w|} + uM_{uw} - qmz_G & 2qM_{q|q|} + uM_{uq} - mwz_G - mux_G \end{bmatrix}$$

(18)

with $Z = CB^2 - ACF + ADE$

$Z_1 = -(CF - DE)$, $Z_2 = -BE$ $Z_3 = BC$, $Z_4 = -BD$, $Z_5 = B^2 - AF$, $Z_6 = AD$, $Z_7 = AE$, $Z_8 = -AC$ dan $A = m - X_{\dot{u}},\ B = mz_G,\ C = m - Z_{\dot{w}},\ D = mx_G + Z_{\dot{q}},\ E = mx_G - M_{\dot{w}},\ F = I_y - M_{\dot{q}}$

with

$$B = \begin{bmatrix} \frac{Z_1}{Z} & \frac{Z_2}{Z} & \frac{Z_3}{Z} \\ \frac{Z_4}{Z} & \frac{Z_5}{Z} & \frac{Z_6}{Z} \\ \frac{Z_3}{Z} & \frac{Z_7}{Z} & \frac{Z_8}{Z} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & Z_{uu\delta_s} u^2 & 0 \\ 0 & 0 & M_{uu\delta_s} u^2 \end{bmatrix} \qquad (19)$$

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \text{ and } D = 0 \qquad (20)$$

3. CONTROLLABILITY AND OBSERVABILITY

Linear system in Equation 18 is said controllable if Matriks : $Ctr = (B|AB|A^2B|\ldots|A^{n-1}B)$ have the n rank. Observable if matriks

$$Obsv = \begin{pmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{(n-1)} \end{pmatrix}$$ have the *n* rank [5].

In equation 19 and 20 obtained controllabity and observability matrix as follows $Ctr = (B|AB|A^2B) = 3$ and

$$Obsv = \begin{pmatrix} C \\ CA \\ CA^2 \end{pmatrix} = 3$$

So linier system of ROV with Jacobian approach is found to be controllable and observable.

4. CONCLUSION

Based on the analysis of Jacobian, controllability and observability ROV system is confirmed. It is also found that linearization of nonlinear ROV system can produce controllable and observable linear ROV system.

REFERENCES

Kondo, H. and Ura, T. (2003), Navigation of an AUV for Investigation of Underwater Structures, . *Elsevier Journal of Control Enginerring Practice.*

Yoerger, D.R. and Slotine, J.J.E. (1985), Robust Trajectory Control of Underwater Vehicle,*IEEE Journal of Ocean Engineering*, 10 (4).

Kim, K.H. and Choi, H.S. (2006), Analysis on the Controlled Nonlinear Motion of Test Bed AUV-SNUUV I, *Elsevier Journal of Ocean Enginerring*

Nurhadi, H., Subchan, and Gustiyadi, F.R. (2012), Design of Position Estimation Algorithm of Navigation and Trajectory System for Unmanned Underwater Vehicle ITS AUV-01 using Ensemble Kalman Filter (EnKF) Method, *Proc. of the 13th Seminar on Intelligent Technology and Its Applications*, SITIA 2012, Surabaya, May.

Perez, T., Smogeli, O.N., Fossen, T.I and Sorensen, A.J. (2005), An Overview of Marine Systems Simulator (MSS): A Simulink Toolbox for Marine Control System,*Proc. of Scandanavian Conference on Simulation and Modelling*, SIMS2005.

Fossen, T.I.(2005), A Nonlinear Unified State-Space Model for Ship Maneuvering and Control in A Seaway, *Journal of Bifurcation and Chaos.*

C, Chin, M.W.S, E. Lan, E and G.G.L, Seet, 2006, “Software for Modelling and Simulation of a Remotely-Operated Vehicle (ROV)”, International Journal Simlation Model Vol 5 no 3, pp114-125.

T.Herlambang, E.B.Djatmiko, and H.Nurhadi “Ensemble Kalman Filter with a Square Root Scheme (EnKF-SR) for Trajectory Estimation of AUV SEGOROGENI ITS”, *International Review of Mechanical Engineering* IREME Journal, Vol. 9, No. 6. Pp. 553-560, ISSN 1970 – 8734. *Nov.* (2015.

T.Herlambang, E.B.Djatmiko, and H.Nurhadi, “Navigation and Guidance Control System of AUV with Trajectory Estimation of Linear Modelling”, *Proc. of International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation,* IEEE , ICAMIMIA 2015, Surabaya, Indonesia, pp. 184-187, Oct 15 – 17. (2015)