Preliminary Numerical Study on Designing Navigation and Stability Control Systems for ITS AUV

[1] Teguh Herlambang, [2] Hendro Nurhadi, [3] Subchan

[1] Department of Ocean Engineering, FTK ITS
[2] Department of Mechanical Engineering, FTI ITS
[3] Department of mathematics, FMIPA ITS
[1]teguh.ftkits@gmail.com, [2]hdnurhadi@me.its.ac.id (corresponding Author),
[3]subchan@matematika.its.ac.id

Keywords: AUV, Nnumerical study, hydrodynamic, navigation, Stability control System.

Abstract. In this paper the numerical study designing on navigation and stabilty control system for AUV are studied. The study started by iniatiating hidrostatic forces, added masses, lift force, drag forces and thrust forces. Ddetermining the hydrodynamic force which is the basic need to know the numerical case study on designing on navigation and stabilty control system for AUV where Autonomous Underwater vehicles (AUV). AUV is capably underwater vehicle in moving automatically without direct control by humans according to the trajectory. The result of numerical study is properly to be the reference for the next developing for AUV.

1. INTRODUCTION

Over than 70%, indonesia is over ocean, so Indonesia potency need attention and good technology is able to determine the full potential of the Indonesians oceans. Underwater robotics technology is very necessary in this case to assist the human to exploration in Indonesian oceans. AUV can be used for underwater exploration, mapping, underwater defense system equipment, sensor off board submarines, inspection of underwater structures natural resources, the condition of the Earth's surface plates etc). Its ability can be controlled, location of its can be monitored from distance even be programmed to move itself through a particular trajectory. But there are many difficulties that need to be resolved before AUV moved as desired are internal and eksternal disturbance.

This study emphasized on basic development of an AUV controlling the navigation and stabilty.

2. Autonomous Underwater Vehicle (AUV) model

Two important things needed to analyze the Autonomous Underwater Vehicle (AUV) that is Earth Fixed Frame (EFF) and Body Fixed Frame (BFF) [1]. EFF is used to describe the position and orientation of the AUV 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 used to describe the speed and acceleration of the AUV with the starting point is at the center of gravity. x-axis direct to the ship's bow, the positive y axis direct to the right side of the ship and the positive z-axis direct down [2,3].

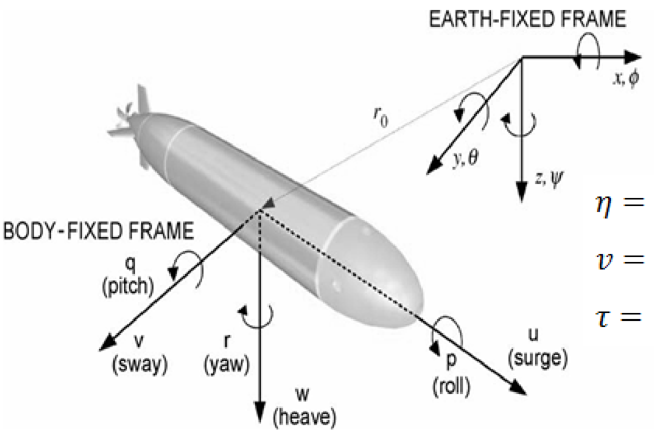
Motion of AUV have 6 DOF where 3 DOF for translational motion and 3 DOF for rotational motion in point x, y and z. The dynamics of the AUV there are external forces influencing the movement follows as [4]:

$$\tau = \tau_{hidrostatis} + \tau_{addedmass} + \tau_{drag} + \tau_{lift} + \tau_{control} \quad \text{(Eq. 1)}$$

General equation of motion in 6 DOF AUV consists of 3 first equation for translational motion and 3 second equation for rotational motion contained in equation 2

Table 1 Notation of AUV Motion Axis [4]

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



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

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

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

Fig. 1 6 DOF in AUV

Where $\boldsymbol{\eta}$ vector potition the position and orientation of the EFF, $\boldsymbol{v}$ vector velocity of linear and anguler of the BFF, the position and orientation of the BFF, and τ description of force and moment in AUV of the BFF.

By combining equations hydrostatic force, lift force, added mass force, drag, thrust force and assuming a diagonal tensor of inertia (I_o) is zero then the total forces and moments of models obtained from the following [1,4].

Translational x :

$$m[\dot{u} - vr + wq - x_G(q^2 + r^2) + y_G(pq - \dot{r}) + z_G(pr + \dot{q})] =$$

$$X_{res} + X_{|u|u}u|u| + X_{\dot{u}}\dot{u} + X_{wq}wq + X_{qq}qq + X_{vr}vr + X_{rr}rr + X_{prop}$$

Translational y :

$$m[\dot{v} - wp + ur - y_G(r^2 + p^2) + z_G(qr - \dot{p}) + x_G(pq + \dot{r})] =$$

$$Y_{res} + Y_{|v|v}v|v| + Y_{r|r|}r|r| + Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + Y_{ur}ur + Y_{wp}wp + Y_{pq}pq + Y_{uv}uv + Y_{uu\delta_r}u^2\delta_r$$

Translational z :

$$m[\dot{w} - uq + vp - z_G(p^2 + q^2) + x_G(rp - \dot{q}) + y_G(rq + \dot{p})] =$$

$$Z_{res} + Z_{|w|w}w|w| + Z_{q|q|}q|q| + Z_{\dot{w}}\dot{w} + Z_{\dot{q}}\dot{q} + Z_{uq}uq + Z_{vp}vp + Z_{rp}rp + Z_{uw}uw + Z_{uu\delta_s}u^2\delta_s \quad \text{(Eq. 2)}$$

Translational x, y and z are representation of surge, sway and heave. 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

Rotational x:

$$I_x\dot{p} + \left(I_z - I_y\right)qr + m[y_G(\dot{w} - uq + vp) - z_G(\dot{v} - wp + ur)] =$$
$$K_{res} + K_{p|p|}p|p| + K_{\dot{p}}\dot{p} + K_{prop}$$

Rotational y :

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

Rotational z :

$$I_z\dot{r} + \left(I_y - I_z\right)pq + m[x_G(\dot{v} - wp + ur) - y_G(\dot{u} - vr + wq)] =$$
$$N_{res} + N_{v|v|}v|v| + N_{r|r|}r|r| + N_{\dot{v}}\dot{v} + N_{\dot{r}}\dot{r} + N_{ur}ur + N_{wp}wp + N_{pq}pq + N_{uv}uv + N_{uu\delta_r}u^2\delta_r \quad \text{(Eq. 3)}$$

Rotational x, y and z are representation of surge, sway and heave. This type of AUV using only one propeller on the tail AUV which will produce x_{prop} and additional momentsK_{prop}. External forces and moments acting on the AUV are the hydrostatic force, thrust force 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 force, drag force and lift force. Thrust force use fin to control the balance of the ship will require a constant rate. Propellers produce forces and moments due to the surge only used only a single propeller.

In this paper there are three case study, te first case study is rotational of z (yawing), the second case study is rotational of y (pitching) and the third case study is rotational of x (rolling).

1. Rotational of z (yawing)
   in this paper, the different of case study is hidrostatic force, in the first case study it assumed only yawing influence, while rolling and pitching no effect and yawing is influenced by gravity and buoyancy force. So we get equation of $(X_{res}, Y_{res}, Z_{res}, K_{res}, M_{res}, N_{res})$ as follows

$$\begin{bmatrix} X_{res} \\ Y_{res} \\ Z_{res} \\ K_{res} \\ M_{res} \\ N_{res} \end{bmatrix} = \begin{bmatrix} -(W - B)\sin\theta \\ (W - B)\cos\theta\sin\emptyset \\ (W - B)\cos\theta\cos\emptyset \\ (y_G W - y_b B)\cos\theta\cos\emptyset - (z_G W - z_b B)\cos\theta\sin\emptyset \\ -(z_G W - z_b B)\sin\theta - (x_G W - x_b B)\cos\theta\cos\emptyset \\ (x_G W - x_b B)\cos\theta\sin\emptyset + (y_G W - y_b B)\sin\theta \end{bmatrix} \text{(Eq. 4)}$$

2. Rotational of y (pitching)
   In the second case study it assumed only pitching influence, while rolling and yawing no effect and pitching is influenced by horizontal fin angle and vertical fin angle. So we get equation of $(X_{res}, Y_{res}, Z_{res}, K_{res}, M_{res}, N_{res})$ as follows

$$\begin{bmatrix} X_{res} \\ Y_{res} \\ Z_{res} \\ K_{res} \\ M_{res} \\ N_{res} \end{bmatrix} = \begin{bmatrix} (\delta_{re} + \delta_{se})\sin\Psi\cos\theta \\ (\delta_{re} + \delta_{se})(\cos\Psi\sin\theta + \sin\emptyset\ \sin\theta\ \sin\Psi) \\ -(\delta_{re} + \delta_{se})(\cos\Psi\sin\emptyset - \cos\emptyset\ \sin\theta\ \sin\Psi) \\ (\delta_{re} + \delta_{se})\left(-y_G(\cos\Psi\sin\emptyset - \cos\emptyset\ \sin\theta\ \sin\Psi) - z_G(\cos\Psi\sin\theta + \sin\emptyset\ \sin\theta\ \sin\Psi)\right) \\ (\delta_{re} + \delta_{se})\left(z_G\sin\Psi + x_G(\cos\Psi\sin\emptyset - \cos\emptyset\ \sin\theta\ \sin\Psi)\right) \\ (\delta_{re} + \delta_{se})(x_G(\cos\Psi\sin\theta + \sin\emptyset\ \sin\theta\ \sin\Psi) - y_G\sin\Psi\cos\theta) \end{bmatrix} \text{(Eq. 5)}$$

3. Rotational of x (rolling)
   In the third case study it assumed only rolling influence, while pitching and yawing no effect and rolling is influenced by horizontal and vertical ocean force. So we get equation of $(X_{res}, Y_{res}, Z_{res}, K_{res}, M_{res}, N_{res})$ as follows

$$\begin{bmatrix} X_{res} \\ Y_{res} \\ Z_{res} \\ K_{res} \\ M_{res} \\ N_{res} \end{bmatrix} = \begin{bmatrix} (g_1 + g_2)\cos\Psi\cos\theta \\ (g_1 + g_2)(-\sin\Psi\cos\emptyset + \cos\Psi\ \sin\emptyset\ \sin\theta) \\ (g_1 + g_2)(\sin\Psi\sin\emptyset + \cos\Psi\cos\emptyset\ \sin\theta) \\ (g_1 + g_2)\big(y_G(\sin\Psi\sin\emptyset + \cos\Psi\cos\emptyset\ \sin\theta) - z_G(-\sin\Psi\cos\emptyset + \cos\Psi\ \sin\emptyset\ \sin\theta)\big) \\ \big(z_G\cos\Psi\cos\theta - x_G(\sin\Psi\sin\emptyset + \cos\Psi\cos\emptyset\ \sin\theta)\big) \\ (g_1 + g_2)(x_G(-\sin\Psi\cos\emptyset + \cos\Psi\ \sin\emptyset\ \sin\theta) - y_G\cos\Psi\cos\theta) \end{bmatrix} \text{(Eq. 6)}$$

Translational and rotational initiative are representation of three case studies. Translational initiative is surge, sway and heave ini figure 2 and rotational initiative is roll, pitch and yaw in figure 3. The numerical result of Translational and rotational initiative in table 2.

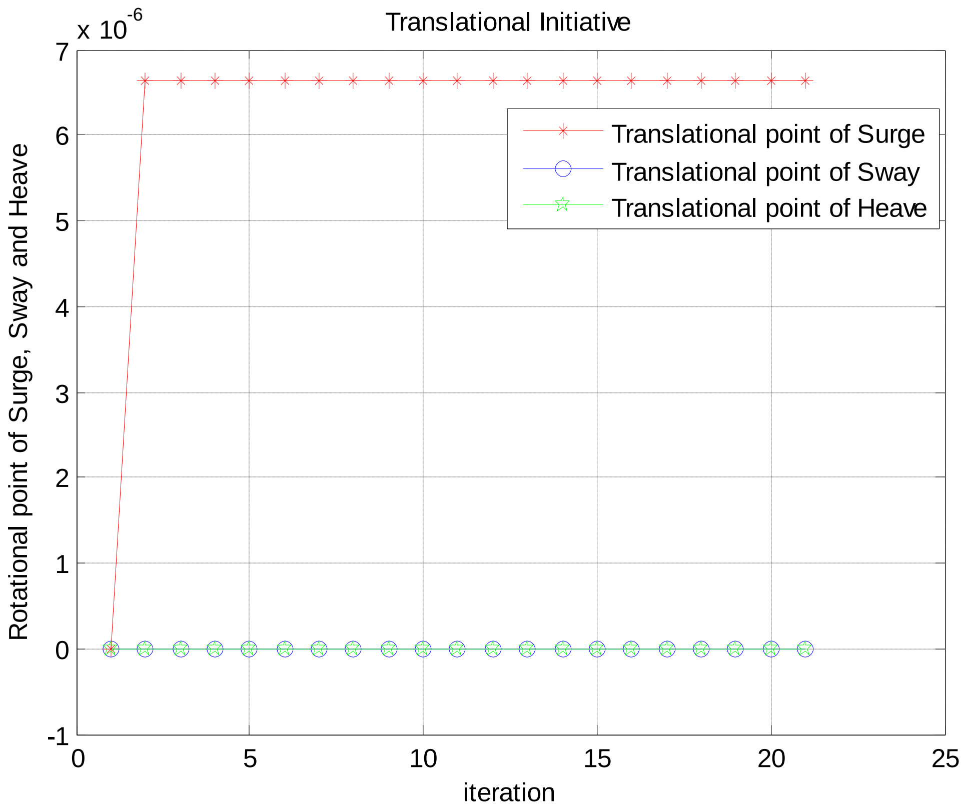


Fig.2 Translational of Surge, Sway and Heave

In figure 2 shows AUV move forward or move to surge axis. While no move to direct sway and heave axis. AUV move to surge axis around 7 x 10^{-6} m/sec while to sway axis around 1,335 x 10^{-6} m/sec and to heave axis around 0,5 x 10^{-6} m/sec.

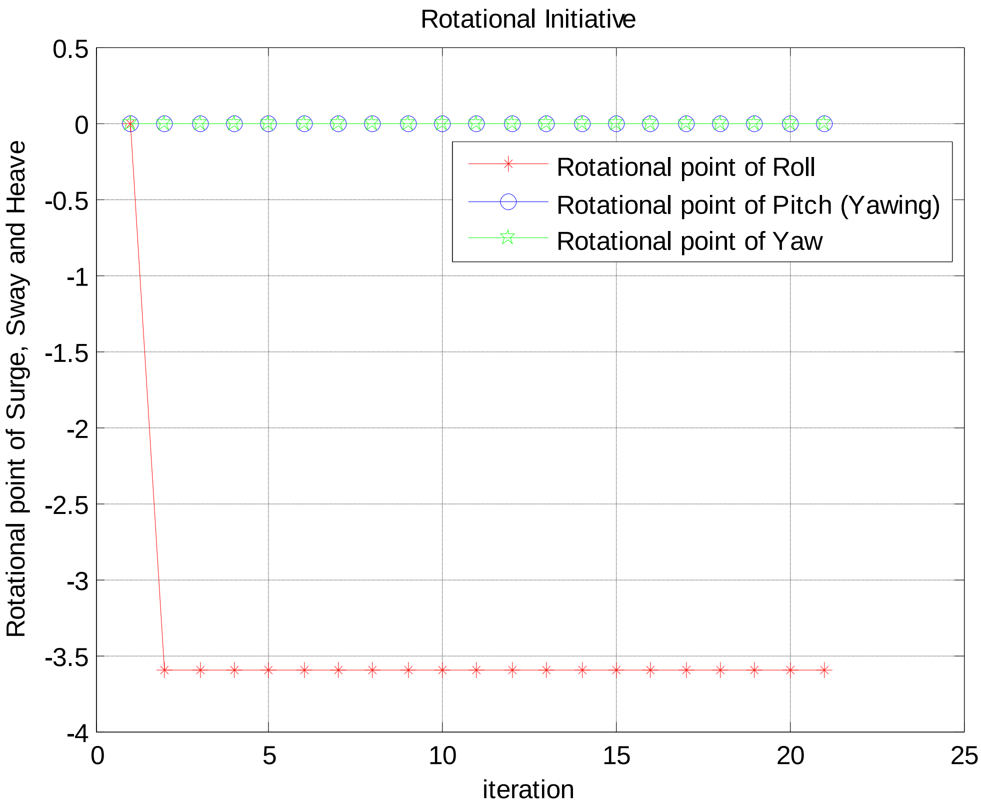


Fig. 3 Rotational of Roll, Pitch and Yaw

In figure 3 shows AUV only rolling while pitch and yaw no move. Rotational point of roll around 1,995 x 10^{-5} rad/sec while Rotational point of pitch around 0,06775 x 10^{-5} rad/sec Rotational point of yaw around 0,015 x 10^{-5} rad/sec.

Assumed in this case is AUV move to forward because disturbance of resistance so rolling effect. from translational and rotational initiative can be reference to control and navigation system.

The purpose of the graph to illustrate the validation of the model in real AUV system without control, navigation and guidance system. So from model validation can be used as numerical preliminary control and navigation design system.

Table 2 Result of translational and rotational initiative Simulation

Translational initiative	Surge	6,45 x 10^{-6}	-
	Sway	1,335 x 10^{-6}	-
	Heave	0,5 x 10^{-6}	-
Rotational initiative	Roll	-	1,995 x 10^{-5}
	Pitch	-	0,6775 x 10^{-5}
	Yaw	-	0,5 x 10^{-5}

Table 2 representation of result simulation translational and rotational initiative. from translational and rotational initiative case can be reference to control and navigation system. In this paper, the result of preliminary study properly orientation on designing navigation and stabilty control.

References

[1] Hendro Nurhadi, Subchan, Gustiyadi Fathur R, Design of Position Estimation Algorithm of Navigation and Trajectory System for Unmanned Underwater Vehicle ITS AUV-01 using Ensemble Kalman Filter (EnKF) Method, *13th Seminar on Intelligent Technology and Its Applications (SITIA 2012)*, Surabaya, 23 May 2012.

[2] T. Perez. O. N. Smogeli, T.I Fossen and A.J Sorensen. 2005. An Overview of marine Systems Simulator (MSS): A Simulink Toolbox for Narine Control System . SIMS2005-Scandanavian Conference on Simulation and Modelling.

[3] T. I. Fossen 2005. A Nonlinear Unified State-space Model for Ship Maneuvering and Control in A Seaway-Journal of Bifurcation and Chaos.

[4] Yang, C. 2007. *Modular Modelling and Control for Autonomous Vehicle (AUV)*. Department of Mechanical Engineering National University of Singapore