Navigation and Guidance Control System of AUV with Trajectory Estimation of Linear Modelling

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***Abstract*—This paper put forwards a study on the development of navigation and guidance systems for AUV. The restriction in AUV model and estimation on the degree of freedom are recognized as the common problem in AUV's navigation and guidance systems. In this respect a linear model, derived from the linearization using the Jacobian matrix, will be utilized. The so obtained linear model is then estimated by the Ensemble Kalman Filter (EnKF). The implementation of EnKF algorithm on the linear model is carried out by establishing two simulations, namely by generating 300 and 400 ensembles, respectively. The simulations exhibit that the generation of 400 ensembles will give more accurate results in comparison to the generation of 300 ensembles. Furthermore, the best simulation yields the tracking accuracy between the real and simulated trajectories, in translational modes, is in the order of 99.88%, and in rotational modes is in the order of 99.99%.**

Keywords— AUV, EnKF, Navigation

I. INTRODUCTION

Over 70% of Indonesia is cover by ocean, so this very potential requires attention and good technology to fully secure the potential of the Indonesian oceans. Underwater robotics technology is very necessary in this case to assist human to do exploration in Indonesian oceans [1]. AUV is very useful for ocean observation since it does not require a tethered cable and so swims freely without restriction [2]. AUV can be used for underwater exploration, mapping and underwater defense system equipment. AUV must clarify its observability and controllability based on a mathematical model [1]. The mathematical model contains various hydrodynamic force and moments expressed collectively in terms of hydrodynamic coefficients [3].

This paper is a study on the development of navigation and guidance systems for AUV. The navigation and guidance is initially modelled as a linear system, derived from the linearization of the non-linear system using the Jacobian matrix, to determine the trajectory in controlling the AUV movement. One of basic Navigation system is trajectory estimation is the Kalman Filter, it is a good candidate method for positioning [4], and we need accurate position estimation [5]. The resulting linear system model is further implemented in the Ensemble Kalman filter (EnKF). In the EnKF method, the algorithm is executed by generating a number of specific ensemble to calculate the mean and covariance error state variables [6].

This paper present trajectory estimation of linear AUV SEGOROGENI ITS system, which is obtain by linearizing nonlinear 6 DOF AUV model with jacobian approach using Ensemble Kalman Filter (EnKF). We present the result of model estimation based on numeric simulation. This paper proposes to validate trajectory estimation of AUV numerically, then it is compared to trajectory reference to get a small root mean square error (RMSE). The implementation of EnKF algorithm on the linear model is carried out by establishing two simulations, namely by generating 300 and 400 ensembles, respectively.

II. AUTONOMOUS UNDERWATER VEHICLE

Two important things required to analyze the Autonomous Underwater Vehicle (AUV) that is Earth Fixed Frame (EFF) and Body Fixed Frame (BFF) in figure 1 [1,5]. EFF is used to describe the position and orientation of the AUV with the position of the x axis 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 AUV with the starting point at the center of gravity [6]. Motion of AUV have 6 DOF where 3 DOF for translational motion and 3 DOF for rotational motion in point x, y and z. Profile and Specification of AUV SEGOROGENI ITS are listed in figure 2 and Table 1.

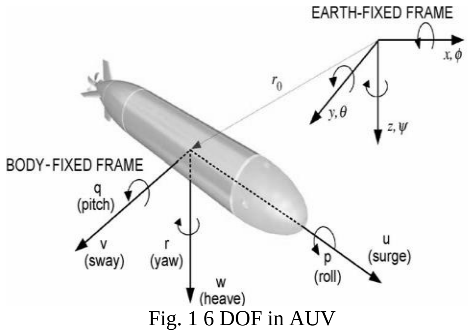

Fig. 1 6 DOF in AUV

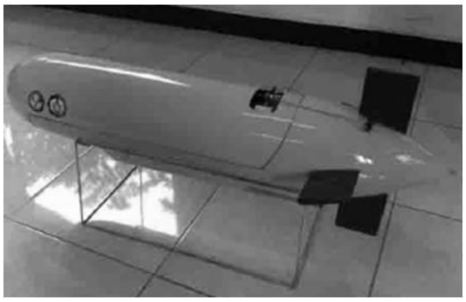

Fig. 2 Profile of AUV SEGOROGENI ITS

Table 2. specification of AUV SEGOROGENI ITS

Weight	15 Kg
Overall Length	980 mm
Beam	180 mm
Controller	Ardupilot Mega 2.0
Communication	Wireless Xbee 2.4 GHz
Camera	TTL Camera
Battery	Li-Pro 11,8 V
Propulsion	12V motor DC
Propeller	3 Blades OD : 40 mm
Speed	1,94 knots (1m/s)

General equation of motion in 6-DOF AUV consists of translational and rotational as follows [9]:

Surge:

$$m[\dot{u} - vr + wq - x_G(q^2 + r^2) + y_G(pq - \dot{r}) + z_G(pr + \dot{q})] = X_{|u|u}u|u| + X_{\dot{u}}\dot{u} + X_{wq}wq + X_{qq}qq + X_{vr}vr + X_{rr}rr + X_{prop} \quad (1)$$

Sway :

$$m[\dot{v} - wp + ur - y_G(r^2 + p^2) + z_G(qr - \dot{p}) + x_G(pq + \dot{r})] = Y_{res} + Y_{|v|v}v|v| + Y_{r|r|}r|r| + Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + Y_{ur}ur + Y_{wp}wp + Y_{pq}pq + Y_{uv}uv + Y_{uu\,\delta_r}u^2\delta_r \quad (2)$$

Heave :

$$m[\dot{w} - uq + vp - z_G(p^2 + q^2) + x_G(rp - \dot{q}) + y_G(rq + \dot{p})] = Z_{res} + Z_{|w|w}w|w| + Z_{q|q|}q|q| + Z_{\dot{w}}\dot{w} + Z_{\dot{q}}\dot{q} + Z_{uq}uq + Z_{vp}vp + Z_{rp}rp + Z_{uw}uw + Z_{uu\,\delta_s}u^2\delta_s \quad (3)$$

Roll:

$$I_x\dot{p} + (I_z - I_y)qr + m[y_G(\dot{w} - uq + vp) - z_G(\dot{v} - wp + ur)] = K_{res} + K_{p|p|}p|p| + K_{\dot{p}}\dot{p} + K_{prop} \quad (4)$$

Pitch :

$$I_y\dot{q} + (I_x - I_z)rp + m[z_G(\dot{u} - vr + wq) - x_G(\dot{w} - uq + vp)] = M_{res} + M_{w|w|}w|w| + M_{q|q|}q|q| + M_{\dot{w}}\dot{w} + M_{\dot{q}}\dot{q} + M_{uq}uq + M_{vp}vp + M_{rp}rp + M_{uw}uw + M_{uu\,\delta_s}u^2\delta_s \quad (5)$$

Yaw :

$$I_z\dot{r} + (I_y - I_z)pq + m[x_G(\dot{v} - wp + ur) - y_G(\dot{u} - vr + wq)] = N_{res} + N_{v|v|}v|v| + N_{r|r|}r|r| + N_{\dot{v}}\dot{v} + N_{\dot{r}}\dot{r} + N_{ur}ur + N_{wp}wp + N_{pq}pq + N_{uv}uv + N_{uu\,\delta_r}u^2\delta_r \quad (6)$$

Translational motion u, v and w are representation of surge, sway and heave. Rotational motion p, q and r are representation of roll, pitch and yaw. The nonlinear system of AUV model can be linearized with Jacobian matrix where the nonlinear AUV system in general as follows :

$$\dot{x}(t) = f(x(t), u(t), t)$$
$$y(t) = g(x(t), u(t), t) \quad (7)$$

So the Jacobian matrix is formed as follows [10] :

$$\frac{\partial f(\bar{x},\bar{u},t)}{\partial x} = \begin{bmatrix} \frac{\partial f_1(\bar{x},\bar{u},t)}{\partial x_1} & \frac{\partial f_1(\bar{x},\bar{u},t)}{\partial x_2} & \cdots & \frac{\partial f_1(\bar{x},\bar{u},t)}{\partial x_n} \\ \frac{\partial f_2(\bar{x},\bar{u},t)}{\partial x_1} & \frac{\partial f_2(\bar{x},\bar{u},t)}{\partial x_2} & \cdots & \frac{\partial f_2(\bar{x},\bar{u},t)}{\partial x_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_n(\bar{x},\bar{u},t)}{\partial x_1} & \frac{\partial f_n(\bar{x},\bar{u},t)}{\partial x_2} & \cdots & \frac{\partial f_n(\bar{x},\bar{u},t)}{\partial x_n} \end{bmatrix} \quad (8)$$

So equation 1 - 6 can be expressed as follows :

$$\begin{bmatrix} 1 & 0 & 0 & 0 & \frac{m z_G}{m - X_{\dot{u}}} & \frac{-m y_G}{m - X_{\dot{u}}} \\ 0 & 1 & 0 & -\frac{m z_G}{m - Y_{\dot{v}}} + & 0 & \frac{(m x_G - Y_{\dot{r}})}{m - Y_{\dot{v}}} \\ 0 & 0 & 1 & \frac{m y_G}{m - Z_{\dot{w}}} & -\frac{(m x_G + Z_{\dot{q}})}{m - Z_{\dot{w}}} & 0 \\ 0 & -\frac{m z_G}{I_x - K_{\dot{p}}} & \frac{m y_G}{I_x - K_{\dot{p}}} & 1 & 0 & 0 \\ \frac{m z_G}{I_y - M_{\dot{q}}} & 0 & -\frac{(m x_G + M_{\dot{w}})}{I_y - M_{\dot{q}}} & 0 & 1 & 0 \\ -\frac{m y_G}{I_z - N_{\dot{r}}} & \frac{(m x_G - N_{\dot{v}})}{I_z - N_{\dot{r}}} & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix} \quad (9)$$

Where $f_1, f_2, f_3, f_4, f_5, f_6$ expressed as follows :

$$f_1 = \frac{X_{res} + X_{|u|u}u|u| + X_{wq}wq + X_{qq}qq + X_{vr}vr + X_{rr}rr + X_{prop} - m[-vr + wq - x_G(q^2 + r^2) + pq\,y_G + pr\,z_G]}{m - X_{\dot{u}}} \quad (10)$$

$$f_2 = \frac{Y_{res} + Y_{|v|v}v|v| + Y_{r|r|}r|r| + Y_{ur}ur + Y_{wp}wp + Y_{pq}pq + Y_{uv}uv + Y_{uu\,\delta_r}u^2\delta_r - m[-wp + ur - y_G(r^2 + p^2) + qr\,z_G + pq\,x_G]}{m - Y_{\dot{v}}} \quad (11)$$

$$f_3 = \frac{Z_{res} + Z_{|w|w}w|w| + Z_{q|q|}q|q| + Z_{uq}uq + Z_{vp}vp + Z_{rp}rp + Z_{uw}uw + Z_{uu\,\delta_s}u^2\delta_s - m[-uq + vp - z_G(p^2 + q^2) + rp\,x_G + rq\,y_G]}{m - Z_{\dot{w}}} \quad (12)$$

$$f_4 = \frac{K_{res} + K_{p|p|}p|p| + K_{prop} - \left((I_z - I_y)qr + m\begin{bmatrix} y_G(-uq + vp) - \\ z_G(-wp + ur) \end{bmatrix}\right)}{I_x - K_{\dot{p}}} \quad (13)$$

$$f_5 = \frac{M_{res} + M_{w|w|}w|w| + M_{q|q|}q|q| + M_{uq}uq + M_{vp}vp + M_{rp}rp + M_{uw}uw + M_{uu\,\delta_s}u^2\delta_s - ((I_x - I_z)rp + m[z_G(-vr + wq) - x_G(-uq + vp)])}{I_y - M_{\dot{q}}} \quad (14)$$

$$f_6 = \frac{N_{res} + N_{v|v|}v|v| + N_{r|r|}r|r| + N_{ur}ur + N_{wp}wp + N_{pq}pq + N_{uv}uv + N_{uu\,\delta_r}u^2\delta_r - ((I_y - I_z)pq + m[x_G(-wp + ur) - y_G(-vr + wq)])}{I_z - N_{\dot{r}}} \quad (15)$$

Furthermore linear system is obtained as follows [7]:

$$\dot{x}(t) = A\,x(t) + Bu(t)$$
$$y(t) = Cx(t) + Du(t) \quad (16)$$

with

$$A = J_x = \begin{bmatrix} 1 & 0 & 0 & 0 & \frac{m z_G}{m - X_{\dot{u}}} & \frac{-m y_G}{m - X_{\dot{u}}} \\ 0 & 1 & 0 & -\frac{m z_G}{m - Y_{\dot{v}}} + & 0 & \frac{(m x_G - Y_{\dot{r}})}{m - Y_{\dot{v}}} \\ 0 & 0 & 1 & \frac{m y_G}{m - Z_{\dot{w}}} & -\frac{(m x_G + Z_{\dot{q}})}{m - Z_{\dot{w}}} & 0 \\ 0 & -\frac{m z_G}{I_x - K_{\dot{p}}} & \frac{m y_G}{I_x - K_{\dot{p}}} & 1 & 0 & 0 \\ \frac{m z_G}{I_y - M_{\dot{q}}} & 0 & -\frac{(m x_G + M_{\dot{w}})}{I_y - M_{\dot{q}}} & 0 & 1 & 0 \\ -\frac{m y_G}{I_z - N_{\dot{r}}} & \frac{(m x_G - N_{\dot{v}})}{I_z - N_{\dot{r}}} & 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} a_1 & b_1 & c_1 & d_1 & e_1 & g_1 \\ a_2 & b_2 & c_2 & d_2 & e_2 & g_2 \\ a_3 & b_3 & c_3 & d_3 & e_3 & g_3 \\ a_4 & b_4 & c_4 & d_4 & e_4 & g_4 \\ a_5 & b_5 & c_5 & d_5 & e_5 & g_5 \\ a_6 & b_6 & c_6 & d_6 & e_6 & g_6 \end{bmatrix} \quad (17)$$

$$B = J_u = \begin{bmatrix} 1 & 0 & 0 & 0 & \frac{m z_G}{m - X_{\dot{u}}} & \frac{-m y_G}{m - X_{\dot{u}}} \\ 0 & 1 & 0 & -\frac{m z_G}{m - Y_{\dot{v}}} + & 0 & \frac{(m x_G - Y_{\dot{r}})}{m - Y_{\dot{v}}} \\ 0 & 0 & 1 & \frac{m y_G}{m - Z_{\dot{w}}} & -\frac{(m x_G + Z_{\dot{q}})}{m - Z_{\dot{w}}} & 0 \\ 0 & -\frac{m z_G}{I_x - K_{\dot{p}}} & \frac{m y_G}{I_x - K_{\dot{p}}} & 1 & 0 & 0 \\ \frac{m z_G}{I_y - M_{\dot{q}}} & 0 & -\frac{(m x_G + M_{\dot{w}})}{I_y - M_{\dot{q}}} & 0 & 1 & 0 \\ -\frac{m y_G}{I_z - N_{\dot{r}}} & \frac{(m x_G - N_{\dot{v}})}{I_z - N_{\dot{r}}} & 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} A_1 & B_1 & C_1 & D_1 & E_1 & G_1 \\ A_2 & B_2 & C_2 & D_2 & E_2 & G_2 \\ A_3 & B_3 & C_3 & D_3 & E_3 & G_3 \\ A_4 & B_4 & C_4 & D_4 & E_4 & G_4 \\ A_5 & B_5 & C_5 & D_5 & E_5 & G_5 \\ A_6 & B_6 & C_6 & D_6 & E_6 & G_6 \end{bmatrix} \quad (18)$$

$$C=\begin{bmatrix}1&0&0&0&0&0\\0&1&0&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\\0&0&0&0&1&0\\0&0&0&0&0&1\end{bmatrix} \text{ and } D=0$$

So
$$\begin{bmatrix}\dot{u}\\\dot{v}\\\dot{w}\\\dot{p}\\\dot{q}\\\dot{r}\end{bmatrix}=A\begin{bmatrix}u\\v\\w\\p\\q\\r\end{bmatrix}+B\begin{bmatrix}X_{prop}\\\delta_r\\\delta_s\\K_{prop}\\\delta_s\\\delta_r\end{bmatrix} \quad (19)$$

Where $a_1, a_2, \ldots, g_6$ and $A_1, A_2, \ldots, G_6$ Component of Matrix A and B (Result of linearization using Jacobian Matrix) in Table 3 and 4.

Table 3. Component of Matrix A

$a_1=\frac{\partial f_1}{\partial u}$	$b_1=\frac{\partial f_1}{\partial v}$	$c_1=\frac{\partial f_1}{\partial w}$
$a_2=\frac{\partial f_2}{\partial u}$	$b_2=\frac{\partial f_2}{\partial v}$	$c_2=\frac{\partial f_2}{\partial w}$
$a_3=\frac{\partial f_3}{\partial u}$	$b_3=\frac{\partial f_3}{\partial v}$	$c_3=\frac{\partial f_3}{\partial w}$
$a_4=\frac{\partial f_4}{\partial u}$	$b_4=\frac{\partial f_4}{\partial v}$	$c_4=\frac{\partial f_4}{\partial w}$
$a_5=\frac{\partial f_5}{\partial u}$	$b_5=\frac{\partial f_5}{\partial v}$	$c_5=\frac{\partial f_5}{\partial w}$
$a_6=\frac{\partial f_6}{\partial u}$	$b_6=\frac{\partial f_6}{\partial v}$	$c_6=\frac{\partial f_6}{\partial w}$
$d_1=\frac{\partial f_1}{\partial p}$	$e_1=\frac{\partial f_1}{\partial q}$	$g_1=\frac{\partial f_1}{\partial r}$
$d_2=\frac{\partial f_2}{\partial p}$	$e_2=\frac{\partial f_2}{\partial q}$	$g_2=\frac{\partial f_2}{\partial r}$
$d_3=\frac{\partial f_3}{\partial p}$	$e_3=\frac{\partial f_3}{\partial q}$	$g_3=\frac{\partial f_3}{\partial r}$
$d_4=\frac{\partial f_4}{\partial p}$	$e_4=\frac{\partial f_4}{\partial q}$	$g_4=\frac{\partial f_4}{\partial r}$
$d_5=\frac{\partial f_5}{\partial p}$	$e_5=\frac{\partial f_5}{\partial q}$	$g_5=\frac{\partial f_5}{\partial r}$
$d_6=\frac{\partial f_6}{\partial p}$	$e_6=\frac{\partial f_6}{\partial q}$	$g_6=\frac{\partial f_6}{\partial r}$

Table 4. Component of Matrix B

$A_1=\frac{\partial f_1}{\partial X_{prop}}$	$B_1=\frac{\partial f_1}{\partial \delta_r}$	$C_1=\frac{\partial f_1}{\partial \delta_s}$
$A_2=\frac{\partial f_2}{\partial X_{prop}}$	$B_2=\frac{\partial f_2}{\partial \delta_r}$	$C_2=\frac{\partial f_2}{\partial \delta_s}$
$A_3=\frac{\partial f_3}{\partial X_{prop}}$	$B_3=\frac{\partial f_3}{\partial \delta_r}$	$C_3=\frac{\partial f_3}{\partial \delta_s}$
$A_4=\frac{\partial f_4}{\partial X_{prop}}$	$B_4=\frac{\partial f_4}{\partial \delta_r}$	$C_4=\frac{\partial f_4}{\partial \delta_s}$
$A_5=\frac{\partial f_5}{\partial X_{prop}}$	$B_5=\frac{\partial f_5}{\partial \delta_r}$	$C_5=\frac{\partial f_5}{\partial \delta_s}$
$A_6=\frac{\partial f_6}{\partial X_{prop}}$	$B_6=\frac{\partial f_6}{\partial \delta_r}$	$C_6=\frac{\partial f_6}{\partial \delta_s}$
$D_1=\frac{\partial f_1}{\partial K_{prop}}$	$E_1=\frac{\partial f_1}{\partial \delta_s}$	$G_1=\frac{\partial f_1}{\partial \delta_r}$
$D_2=\frac{\partial f_2}{\partial K_{prop}}$	$E_2=\frac{\partial f_2}{\partial \delta_s}$	$G_2=\frac{\partial f_2}{\partial \delta_r}$
$D_3=\frac{\partial f_3}{\partial K_{prop}}$	$E_3=\frac{\partial f_3}{\partial \delta_s}$	$G_3=\frac{\partial f_3}{\partial \delta_r}$
$D_4=\frac{\partial f_4}{\partial K_{prop}}$	$E_4=\frac{\partial f_4}{\partial \delta_s}$	$G_4=\frac{\partial f_4}{\partial \delta_r}$
$D_5=\frac{\partial f_5}{\partial K_{prop}}$	$E_5=\frac{\partial f_5}{\partial \delta_s}$	$G_5=\frac{\partial f_5}{\partial \delta_r}$
$D_6=\frac{\partial f_6}{\partial K_{prop}}$	$E_6=\frac{\partial f_6}{\partial \delta_s}$	$G_6=\frac{\partial f_6}{\partial \delta_r}$

III. ENSEMBLE KALMAN FILTER

The algorithm *Ensemble Kalman Filter* (EnKF) can be seen [11]:

Model system and measurement model

$$x_{k+1}=f(x_k,u_k)+w_k \quad (20)$$

$$z_k=Hx_k+v_k \quad (21)$$

$$w_k \sim N(0,Q_k),\ v_k \sim N(0,R_k) \quad (22)$$

1. Inisialitation

   Generate N *ensemble* as the first guess $\bar{x}_0$

   $$x_{0,i}=[x_{0,1} \quad x_{0,2} \quad \cdots \quad x_{0,N}] \quad (23)$$

   The first value: $\hat{x}_0=\frac{1}{N}\sum_{i=1}^{N}x_{0,i}$ (24)

2. Time Update

   $\hat{x}_{k,i}^{-}=f(\hat{x}_{k,-1,i},u_{k-1,i})+w_{k,i}$ where $w_{k,i}=N(0,Q_k)$ (25)

   Estimation :$\hat{x}_k^{-}=\frac{1}{N}\sum_{i=1}^{N}\hat{x}_{k,i}^{-}$ (26)

   Error *covariance*:

   $$P_k^{-}=\frac{1}{N-1}\sum_{i=1}^{N}(\hat{x}_{k,i}^{-}-\hat{x}_k^{-})(\hat{x}_{k,i}^{-}-\hat{x}_k^{-})^T \quad (27)$$

3. Measurement Update

   $z_{k,i}=Hx_{k,i}+v_{k,i}$ where $v_{k,i}\sim N(0,R_k)$ (28)

   Kalman gain : $K_k=P_k^{-}H^T(HP_k^{-}H^T+R_k)^{-1}$ (29)

   Estimation : $\hat{x}_{k,i}=\hat{x}_{k,i}^{-}+K_k(z_{k,i}-H\hat{x}_{k,i}^{-})$ (30)

   $\hat{x}_k=\frac{1}{N}\sum_{i=1}^{N}\hat{x}_{k,i}$ (31)

   Error covariance : $P_k=[I-K_kH]P_k^{-}$ (32)

IV. COMPUTATIONAL RESULT

This simulation was carried out by implementing an algorithm Ensemble Kalman Filter (EnKF) in the AUV model. The result of the simulation was evaluated and compared with real condition, estimaton result by EnKF. This simulation consist of two types of simulations. That is the first simulation by generating 300 ensemble and the second simulation by generating 400 ensembles. The simulations were conducted by assuming surge (u), sway (v), heave (w), roll (p), pitch $(q)$and yaw (r). The value of Δt has been used was $\Delta t=0{,}1$. The initial condition used were $u_0=0\,m, v_0=0\,m,\ w_0=0\,m, p_0=0\,rad,\ q_0=0\,rad$ and $r_0=0\,rad$.

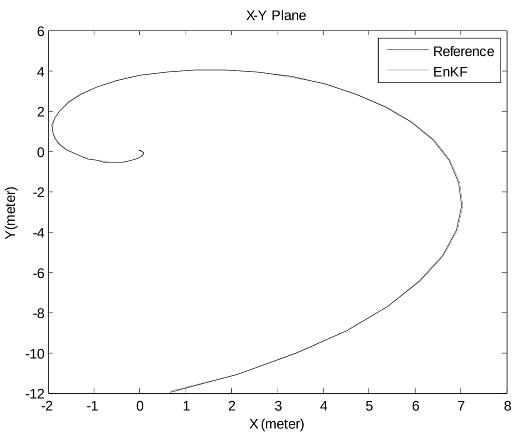

Figure 2. Trajectory Estimation of 6 DOF for XY Plane with 400 ensemb

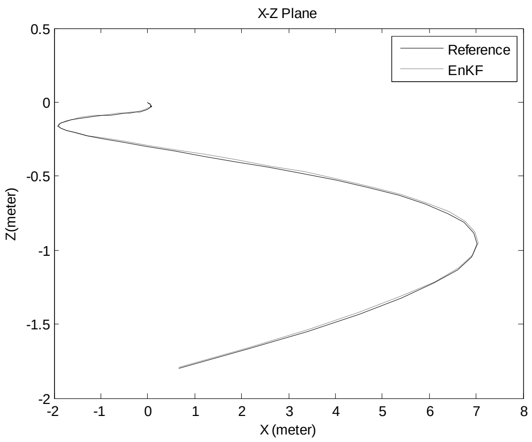

Figure 3. Trajectory Estimation of 6 DOF for XZ Plane with 400 ensemble

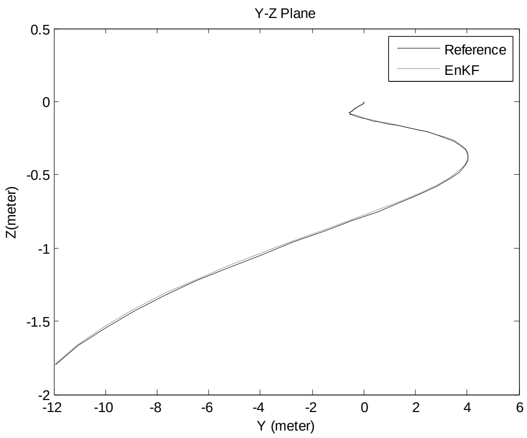

Figure 4. Trajectory Estimation of 6 DOF for YZ Plane with 400 ensemble

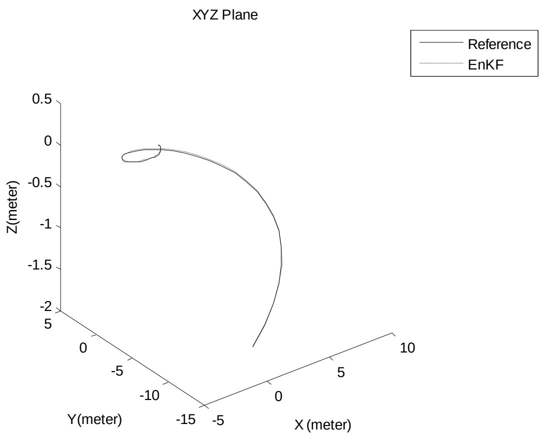

Figure 5. Trajectory Estimation of 6 DOF for XYZ Plane with 400 ensemble

Figure 2, 3, 4 and 5 shows AUV moves following the desire trajectory both on XY, XZ, YZ and XYZ plane with high accuracy. In figure 2, AUV goes to the left and then turn arround clock wise. In fiu 3, AUV dives by turning right and left until depth of 1,9 meter. In general as seen in the Table 5, the results of the two simulations were highly accurate. The first simulation by generate 300 ensemble with tracking error of translational motion 0,0082 m/s or accuracy of 99,82% and rotational motion 0,00099 rad/s or accuracy of 99,99%. the second simulation by generate 400 ensemble with tracking error of translational motion 0,007 m/s or accuracy of 99,88% and rotational motion 0,00091 rad/s or accuracy of 99,99%. Time simulation of the two simulation results with 300 ensemble faster than 400 because more ensemble generated the longer time simulation.

Table 5. RMSE value from Computational Result

	300 Ensemble		400 Ensemble	
	RMSE	Accuracy	RMSE	Accuracy
Surge	0.0071 m/s	99,98%	0.0077m/s	99,96%
Sway	0.0094m/s	99,8%	0.0071m/s	99,93%
Heave	0.0081m/s	99,7%	0.0063 m/s	99,75%
Roll	0.00099 rad/s	99,99%	0.00098 rad/s	99,99%
Pitch	0.00094 rad/s	99,99%	0.00088 rad/s	99,99%
Yaw	0.00105rad/s	99,99%	0.00088 rad/s	99,99%
Time	3.8125 s		5.0469 s	

V. CONCLUSION

Based on analysis of the two simulation results, EnKF method could be applied to estimate of linear system trajectory of AUV SEGOROGENI ITS with considerably high accuracy. Of the two simulation by generating both 300 and 400 ensembles, the estimation results were all accurate.

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