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Abstract. An Autonomous Surface Vehicle (ASV) is a vehicle in the form of a ship on the surface of the water that can move without a crew on it or operate automatically. This study used the Touristant ASV with a length of 4 meters, a diameter of 1.5 meters, and a height of 1.3 meters. The contribution of this paper is the estimation of ASV position and ASV motion influenced by wind speed and wave height. The estimation method used is the Ensemble Kalman Filter (EnKF) method. EnkF is applied to the nonlinear ASV model to obtain a small position error. In our simulations, we conducted 3 scenarios based on the number of generated ensembles, that are 100, 200 and 300 ensembles. The position error generated from the simulation showed that the simulation with the lower position error has an accuracy more than 95%. The position error of x is 0.009 meters, the position error of y is 0.008 meters, and the position error of XY plane is 0.01 meters.

INTRODUCTION

Indonesia is an archipelagic country, consisting of 17,508 islands, with about two-thirds of sea territory, and with several major islands [1]. This can provide income opportunities for the country, especially in the marine tourism sector. One of the marine water tourisms in Indonesia is Kenjeran beach. Kenjeran Beach is one of the tourism objects located in Surabaya presenting various natural treats of the ocean and coastal environment along with the beauty of the Suramadu Bridge which is the longest bridge in Indonesia. To enjoy the beauty, Kenjeran Beach provides simple boats operated by humans. Simple boats operation by humans may cause accidents due to human's negligence, lack of professionalism and some other factors. One solution to reduce accidents and keep up with technology to support the tourism sector, especially on Kenjeran Beach, is utilizing an Autonomous Surface Vehicle (ASV).

In Indonesia, the development of Autonomous Surface Vehicle (ASV) technology is quite fast. Unmanned Surface Vehicle (USV) or ASV is a ship robot that can move automatically from one point to another. This automatic movement uses position estimation of ASV. Several studies have been carried out regarding the estimation of positions such as the one applied to AUV using Ensemble Kalman Filter [2] and Square Root Ensemble Kalman Filter (SR-EnKF) method [3] and Fuzzy Kalman Filter [4], and that applied on missiles using SR-EnKF [5]. Position estimation has also been applied to ASV using the Kalman Filter method [6], then in 2013, track estimates were applied to ASV using the Neural Network [7].

In this paper, the position estimation was applied to the 3-DOF nonlinear model (surge, sway and yaw), where the ASV prototype used is a Touristant ASV with a length of 4 meters which can carry 2 passengers. The position estimation is conducted using the Ensemble Kalman Filter method, which is an extension of the Kalman Filter method for nonlinear models. ASV position estimation is useful for monitoring the ASV position to ensure whether it has been

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going through a predetermined path. The contribution of this paper is the estimation of ASV position and the ASV motion influenced by wind speed and wave height.

AUTONOMOUS SURFACE VEHICLE

ASV is equipped with GPS (Global Positioning System), sensors, gas, pH sensors, bluetooth, and telemetry. When the location has been determined, the ship will move automatically in real-time. ASV can be used, other than as a research vessel, for a survey ship, inspection of river conditions, seismic surveys, rescue operations and some similar problems. The profile and specifications of Touristant ASV are shown in Fig. 1 and Table 1.

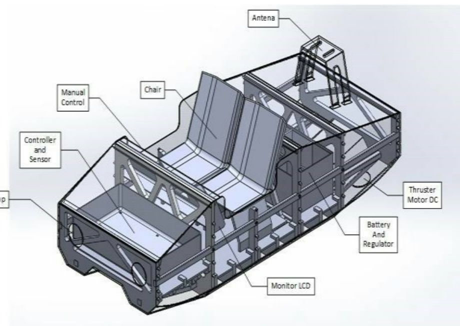

FIGURE 1. Profile of Touristant ASV

TABLE 1. Specification of Touristant ASV

Length	4.12 m
Bean	1.625 m
Depth	1.027 m
DWL	0.3 m
AP	-2.618 m
FP	2.618 m

In general, ship motions are divided into two movement types: translational and rotational motions. Translational motion is divided into three motions: surge, sway and heave. Rotational motion is divided into three motions: roll, pitch, and yaw [4]. In this paper, we use the equation of ship motions with 3 degrees of freedom out of 6 degrees of freedom namely surge, sway and, yaw [8].

We use the simplified nonlinear model in [4]. The equations for surge, sway and yaw are described in the following equations [8]:

$$(m - X_{\dot{u}})\dot{u} = X_{|u|u}|u|u + (1-h)X_{prop} + (m + X_{vr})vr + (mx_G + X_{rr})r^2 + X_{\delta\delta}\delta^2 + X_{ext}, \quad (1)$$

$$(m - Y_{\dot{v}})\dot{v} + (mx_G - Y_{\dot{r}})\dot{r} = -(m - Y_{ur})ur + Y_{uv}uv + Y_{|v|v}|v|v + Y_{|v|r}|v|r + Y_{\delta}\delta + Y_{ext}, \quad (2)$$

$$(mx_G - N_{\dot{v}})\dot{v} + (I_z - N_{\dot{r}})\dot{r} = -(mx_G - N_{ur})ur + N_{uv}uv + N_{|v|v}|v|v + N_{|v|r}vr + N_{\delta}\delta + N_{ext}, \quad (3)$$

where X_{ext}, Y_{ext} and N_{ext} are external interferences to the motion of surge, sway and yaw, respectively. In this study, the external interference or environmental factors are considered as the force against wind speed and that against wave height and moment of wind speed and force against wave height. So, the equations are as follows:

$$X_{ext} = X_{wind} + X_{waves}, \quad (4)$$

$$Y_{ext} = Y_{wind} + Y_{waves}, \quad (5)$$

$$N_{ext} = N_{wind} + N_{waves}. \quad (6)$$

From the description of X_{ext}, Y_{ext} and N_{ext}, the nonlinear model can be written as follows:

$$(m - X_{\dot{u}})\dot{u} = X_{|u|u}|u|u + (1-h)X_{prop} + (m + X_{vr})vr + (mx_G + X_{rr})r^2 + X_{\delta\delta}\delta^2 + X_{wind} + X_{waves}, \quad (7)$$

$$(m - Y_{\dot{v}})\dot{v} + (mx_G - Y_{\dot{r}})\dot{r} = -(m - Y_{ur})ur + Y_{uv}uv + Y_{|v|v}|v|v + Y_{|v|r}|v|r + Y_{\delta}\delta + Y_{wind} + Y_{waves}, \quad (8)$$

$$(mx_G - N_{\dot{v}})\dot{v} + (I_z - N_{\dot{r}})\dot{r} = -(mx_G - N_{ur})ur + N_{uv}uv + N_{|v|v}|v|v + N_{|v|r}vr + N_{\delta}\delta + N_{wind} + N_{waves}. \quad (9)$$

The nonlinear model (7)-(9) is quite complicated because the model contains many variables and parameters. In order to simplify the model, we introduce three variables U_{surge}, V_{sway}, N_{yaw} as follows:

$$U_{surge} = X_{|u|u}|u|u + (m + X_{vr})vr + (mX_G + X_{rr})r^2 + X_{\delta\delta}\delta^2 + X_{wind} + X_{waves}, \quad (10)$$

$$V_{sway} = -(m - Y_{ur})ur + Y_{uv}uv + Y_{|v|v}|v|v + Y_{|v|r}|v|r + Y_{wind} + Y_{waves}, \quad (11)$$

$$N_{yaw} = -(mX_G - N_{ur})ur + N_{uv}uv + N_{|v|v}|v|v + N_{|v|r}vr + N_{wind} + N_{waves}. \quad (12)$$

By using the introduced three variables, the nonlinear model can be written as

$$(m - X_{\dot{u}})\dot{u} = (1-h)X_{prop} + U_{surge}, \quad (13)$$

$$(m - Y_{\dot{v}})\dot{v} + (mX_G - Y_{\dot{r}})\dot{r} = Y_{\delta}\delta + V_{sway}, \quad (14)$$

$$(mX_G - N_{\dot{v}})\dot{v} + (I_z - N_{\dot{r}})\dot{r} = N_{\delta}\delta + N_{yaw}. \quad (15)$$

From (13)-(15), we can construct the nonlinear model in a state space form as follows:

$$\dot{u} = T_1\big((1-t)X_{prop} + U_{surge}\big), \quad (16)$$

$$\dot{v} = T_2\big(Y_{\delta}\delta_1 + V_{sway}\big) + T_3\big(N_{\delta}\delta_1 + N_{yaw}\big), \quad (17)$$

$$\dot{r} = T_4\big(Y_{\delta}\delta_2 + V_{sway}\big) + T_5\big(N_{\delta}\delta_2 + N_{yaw}\big), \quad (18)$$

ENSEMBLE KALMAN FILTER

Ensemble Kalman Filter (EnKF) is an estimation method that is an extension of Kalman Filter [18]. Kalman Filter is an estimation method for stochastic discrete-time linear systems. EnKF is an estimation method for stochastic discrete-time nonlinear systems. In EnKF, the nonlinearity of the system is represented by a collection of randomly generated vectors called ensemble. The general form of stochastic discrete-time nonlinear systems is

$$x_{k+1} = f(x_k, u_k) + w_k, \quad (19)$$

$$z_k = Hx_k + v_k, \quad (20)$$

where x_k is the state variable, z_k is the measured variable, u_k is the input variable, $w_k \sim N(0, Q_k)$ is the system noise and $v_k \sim N(0, R_k)$ is the measurement noise. The EnKF algorithm is as follows:

1. Initialization

The initial state is assumed to follow normal distribution with mean $\bar{x}_0$ and covariance P_0. Generate N ensemble for the initial state denoted by $x_{0,i} = [x_{0,1} \quad x_{0,2} \quad \cdots \quad x_{0,N}]$. The initial state is defined as the mean of the ensemble $\hat{x}_0 = \frac{1}{N}\sum_{i=1}^{N} x_{0,i}$.

2. Time Update

Compute the ensemble representing the prediction of state $\hat{x}_{k,i}^{-} = f\left(\hat{x}_{k,-1,i}, u_{k-1,i}\right) + w_{k,i}$, for $i = 1, \dots, N$ where $w_{k,i} \sim N(0, Q_k)$ is a normally distributed random variable with mean 0 and variance Q_k. The estimation of the next state is defined as the mean of the ensemble $\hat{x}_k^{-} = \frac{1}{N}\sum_{i=1}^{N} \hat{x}_{k,i}^{-}$. The error covariance is given by $P_k^{-} = \frac{1}{N-1}\sum_{i=1}^{N}\left(\hat{x}_{k,i}^{-} - \hat{x}_k^{-}\right)\left(\hat{x}_{k,i}^{-} - \hat{x}_k^{-}\right)^T$.

3. Measurement Update

Compute the ensemble representing the measurement $z_{k,i} = Hx_{k,i} + v_{k,i}$, for $i = 1, \dots, N$ where $v_{k,i} \sim N(0, R_k)$ is a normally distributed random variable with mean 0 and variance R_k. Then the Kalman gain in computed by using $K_k = P_k^{-}H^T\left(HP_k^{-}H^T + R_k\right)^{-1}$. The ensemble of state estimation is updated by using $\hat{x}_{k,i} = \hat{x}_{k,i}^{-} + K_k\left(z_{k,i} - H\hat{x}_{k,i}^{-}\right)$, for $i = 1, \dots, N$. The estimation of next state is also updated $\hat{x}_k = \frac{1}{N}\sum_{i=1}^{N} \hat{x}_{k,i}$. The error covariance becomes $P_k = [I - K_kH]P_k^{-}$.

COMPUTATIONAL RESULTS

The simulation was conducted by applying the Ensemble Kalman Fillter (EnKF) algorithm in the Touristant ASV nonlinear model. The estimation results were evaluated, and the real condition was compared to the results of the estimation by using EnKF method.Three scenarios were carried out based on the number of ensembles. In the first scenario, we generate 100 ensembles. For the second and third scenarios, 200 and 300 ensembles are generated, respectively.

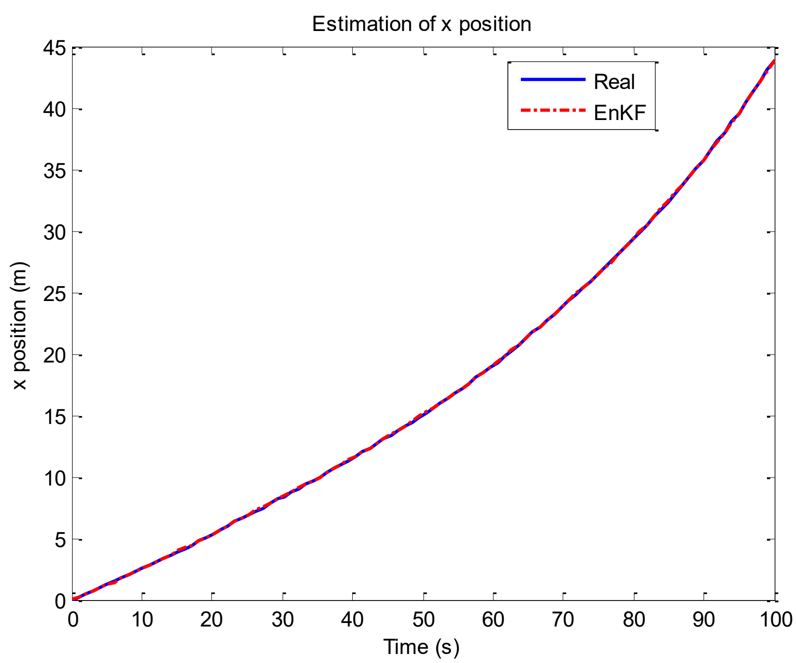

FIGURE 2. Comparison between the estimation of x position obtained from the EnKF algorithm and the real values.

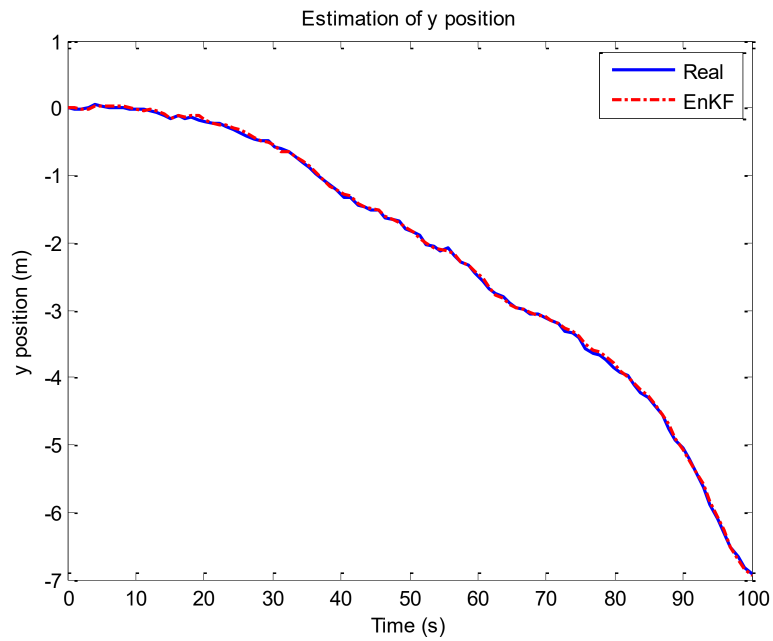

FIGURE 3. Comparison between estimation of y position obtained from the EnKF algorithm and the real values

Figures 2 and 3 show that the Touristant ASV moves along the path that has been made at the x coordinate, where the EnKF method has a small x position error and high accuracy (around 95%). The error obtained by generating 300 ensembles for position X is 0.011 and for position Y is 0.007 m. This means the deviation is approximately 0.7 cm from the target to be traveled around 9 m.

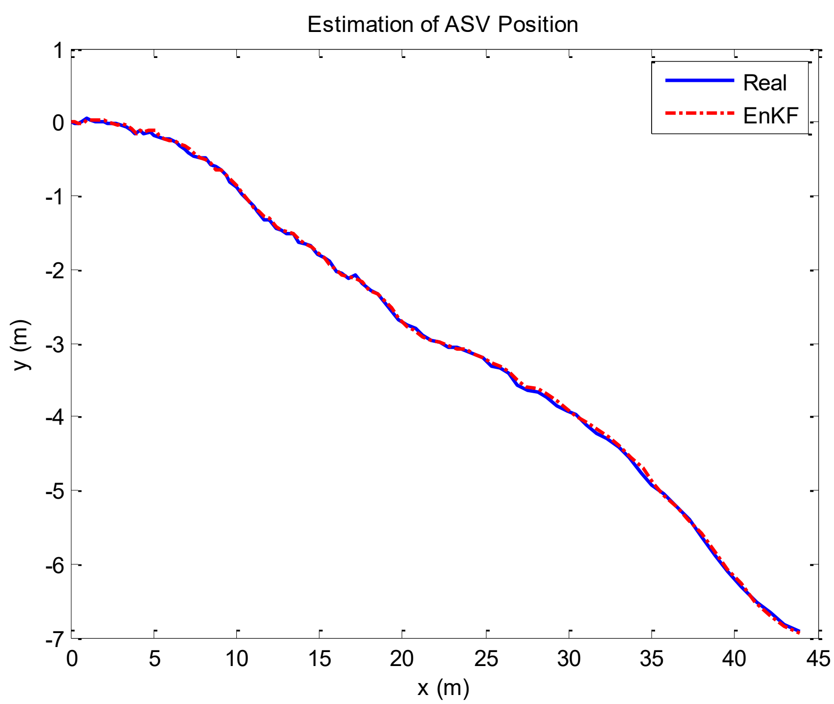

FIGURE 4. Position estimation of Touristant ASV by using Ensemble Kalman Filter and the true position of Touristant ASV

Figure 4 shows that the AUV also follows the path in the XY plane by moving forward and dragging to the left. The length of forward motion is around 45 meters and the time of simulation is 100 seconds. From the graph, it can be seen that the EnKF method has a very high accuracy around 95% -97%.

In Table 2, it seems that by generating 300 ensembles, the accuracy is higher than those generating 100 and 200 ensembles. However, the simulation results show that the EnKF method has high accuracy by generating either 100, 200 or 300 ensembles. Thus, it can be concluded that the implementation of the EnKF method on an ASV platform can be performed.

TABLE 2. RMSE obtained from the experimental results.

	100 Ensemble	**200 Ensemble**	**300 Ensemble**
X Position	0.0093912 m	0.009289 m	0.009145 m
Y Position	0.009147 m	0.008951 m	0.008567 m
XY Plane	0.0187 m	0.0168 m	0.0156 m
Computational time	4.56 sec	7.231 sec	10.3 sec

CONCLUSIONS

According to the simulation results, we conclude that the Ensemble Kalman Filter (EnKF) method could be effectively applied to estimate the trajectory of Touristant ASV with high accuracy. If the number of generated ensembles is higher, the accuracy is also higher. It can be seen from the simulation results that the estimation accuracy of EnKF that generates 300 ensembles is higher than 100 and 200 ensembles.

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