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A Remotely Operated Vehicle Tracking Model Estimation Using Square Root Ensemble Kalman Filter and Particle Filter

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Abstract: A ROV (Remotely Operated Vehicle) is a product of technological development that functions to perform tasks in the water. Major tasks are coral reef exploration, oil refineries, underwater monitoring, and at-sea accident rescue. The ROV or unmanned submarines have 6 degrees of freedom. In operation, the ROV requires a navigation system, that is, ROV position estimation in its diving and emerging. Some reliable motion estimation methods frequently used are the Ensemble Kalman Filter Square Root (EnKF-SR) and Particle Filter methods. The EnKF method is used to estimate the state of a dynamic system, and it is used in various fields such as meteorology, hydrology, ecology, geophysics, and robotics. Whereas the Particle Filter one is a powerful tool to handle monitoring, estimation, and prediction problems in various contexts involving uncertainty and dynamic changes. And this paper performs the ROV diving and emerging motion estimation using the EnKF-SR and Particle Filter methods. Both methods are proven to be reliable on other platforms. The simulation results in this paper showed that the EnKF method has a higher accuracy than the Particle Filter one by showing an accuracy of 98% by the Particle Filter method and an accuracy of 99% by the EnKF-SR method.

Keywords: *ROV; estimation; ensemble Kalman filter, EnKF-SR, particle filter.*

Mathematics Subject Classification (2010): 93C10, 93D05.

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1 Introduction

Indonesia is an archipelago country, therefore it requires a vehicle for its underwater mapping and maintenance. One of such vehicles is a Remotely Operated Vehicle (ROV), a vehicle that operates under the sea and is controlled by an operator from land. In operation, the ROV requires a navigation system to know the position of the ROV. Its position is then used by the operator to control the ROV motion to the desired place [1].

The ROV can be used for the inspection of underwater structures such as oil and gas pipelines, subsea cables, renewable energy installations, and other underwater facilities [2]. ROVs allow repairs and maintenance to be done without the need for human diving which can be dangerous and costly, and they are frequently used for search and rescue operations, especially in the case of missing submarines or aircraft. The ROV can assist in searches, identify locations, and provide vital information for rescue teams [3, 4].

In addition to ROVs, there are AUVs (Autonomous Underwater Vehicles) having almost the same function. In the AUV, the control is automatic. So, to carry out a mission, the AUV is given a special program to perform certain tasks, then the robot does them according to the program without being controlled by a pilot/operator. The AUV itself requires batteries to do its job, so the time to do its mission is very limited. The advantage of the ROV is that since it is connected to a data cable and a power cable, its use can be very long and maximized [5]. The pilot/operator in moving the ROV usually uses the camera in the ROV and then displays it on the monitor screen to monitor whatever is seen in the water. The ROV various sensors are usually installed to monitor various indicators while its operation in the water, namely water density, temperature, current, etc [6].

This study started with the modeling of the 6-DOF motion equation by combining rotational and translational motions. Then the position estimation method was applied to determine the movements of the ROV when diving underwater. Some of the position estimation methods for ROV or AUV motion estimation ever applied in the previous studies were the Fuzzy Kalman Filter [7], Extended Kalman Filter [8, 9], EnKF-SR [10], Unscented Kalamn Filter [11], H-Infinity [12] and EnKF [13, 14]. Of the six position estimation methods above, the EnKF and Particle Filter methods were applicable to both linear and nonlinear models. The EnKF method is used to estimate the state of the dynamic system. It can be used in various fields such as meteorology, hydrology, ecology, geophysics, and robotics. The Particle Filter is a powerful tool to handle monitoring, estimation, and prediction problems in various contexts involving uncertainty and dynamic changes. And the study of this paper is to estimate the ROV diving motion by using the EnKF and Particle Filter methods.

2 Remotely Operated Vehicle (ROV) with 6-DOF

The profile of the ROV can be seen in Figure 1 and the specifications of the ROV can be seen in Table 1.

This study focused on the diving and emerging motion only so as to observe 6 Degrees of Freedom for which the motion equations are as follows [14]:

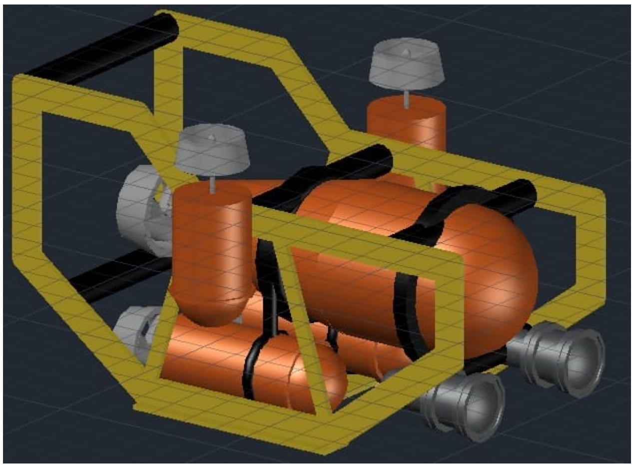

Figure 1: Profile of Rescue ROV [5, 6].

Table 1: Specifications of Rescue ROV [5, 6].

Weight	15 Kg
Length Length	900 mm
Beam	300 mm
Controller	Wired Control ArduSUB with Joystick
Sensors	Depth Sensor, Sonar
Camera	TTL Camera
Lighting	1500 LM, 145° Beam Dimmable
Battery	11.8 V Li Po 5200 mAh
Material	Carbon Fiber
Main Propulsion	T200 Motor Thruster Include Propeller
Maneuver Propulsion	T200 Motor Thruster Include Propeller
Service Speed	1, 6 knots
Operation Depth	5 – 10 m

Surge:

$$\dot{u} + \frac{mz_G\dot{q}}{m - X_{\dot{u}}} - \frac{my_G\dot{r}}{m - X_{\dot{u}}} = \left(\frac{1}{m - X_{\dot{u}}}\right)\big(X_{res} + X_{|u|u}u|u| + X_{\dot{u}}\dot{u} + X_{wq}wq + X_{qq}qq + X_{vr}vr + X_{rr}rr + X_{prop} - m\left[-vr + wq - x_G(q^2 + r^2) + pqy_G + prz_G\right]\big)\,; \quad (1)$$

Sway:

$$\dot{v} + \frac{mz_G\dot{p}}{m - Y_{\dot{v}}} + \frac{(mx_G - Y_{\dot{r}})\dot{r}}{m - Y_{\dot{v}}} = \left(\frac{1}{m - Y_{\dot{v}}}\right)\big(Y_{res} + Y_{|v|v}v|v| + Y_{r|r|}r|r| + Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + Y_{ur}ur + Y_{wp}wp + Y_{pq}pq + Y_{uv}uv + Y_{uu\delta_r}u^2\delta_r - m[-wp + ur - y_G(r^2 + p^2) + qrz_G + pqx_G]\big)\,; \quad (2)$$

Heave:

$$\dot{w} + \frac{(mx_G + Z_{\dot{q}})\dot{q}}{m - Z_{\dot{w}}} + \frac{my_G\dot{p}}{m - Z_{\dot{w}}} = \left(\frac{1}{m - Z_{\dot{w}}}\right)\big(Z_{res} + Z_{|w|w}w|w| + Z_{q|q|}q|q| + Z_{\dot{w}}\dot{w} + Z_{\dot{q}}\dot{q} + Z_{uq}uq + Z_{vp}vp + Z_{rp}rp + Z_{uw}uw + Z_{uu\delta_s}u^2\delta_s - m[-uq + vp - z_G(p^2 + q^2) + rpx_G + rqy_G]\big)\,; \quad (3)$$

Roll:

$$\dot{p} + \frac{my_G\dot{w}}{I_x - K_{\dot{p}}} - \frac{mz_G\dot{v}}{I_x - K_{\dot{p}}} = \left(\frac{1}{I_x - K_{\dot{p}}}\right)\left(K_{res} + K_{p|p|}p|p| + K_{prop} - \right.$$
$$\left.((I_z - I_y)qr + m[y_G(-uq + vp) - z_G(-wp + ur)])\right); \tag{4}$$

Pitch:

$$\dot{q} + \frac{mz_G\dot{u}}{I_y - M_{\dot{q}}} - \frac{(mx_G + M_{\dot{w}})\dot{w}}{I_y - M_{\dot{q}}} = \left(\frac{1}{I_y - M_{\dot{q}}}\right)\left(M_{res} + M_{w|w|}w|w| + M_{q|q|}q|q| + \right.$$
$$M_{\dot{w}}\dot{w} + M_{\dot{q}}\dot{q} + M_{uq}uq + M_{vp}vp + M_{rp}rp + M_{uw}uw + M_{uu\delta_s}u^2\delta_s -$$
$$\left.(I_x - I_z)rp + m[z_G(-vr + wq) - x_G(-uq + vp)]\right); \tag{5}$$

Yaw:

$$\dot{r} + \frac{(mx_G - N_{\dot{v}})\dot{v}}{I_z - N_{\dot{r}}} - \frac{my_G\dot{u}}{I_z - N_{\dot{r}}} = \left(\frac{1}{I_z - N_{\dot{r}}}\right)\left(N_{res} + N_{|v|v}v|v| + N_{r|r|}r|r| + N_{ur}ur + \right.$$
$$N_{wp}wp + N_{pq}pq + N_{uv}uv + N_{uu\delta_r}u^2\delta_r - ((I_y - I_z)pq +$$
$$\left.m[x_G(-wp + ur) - y_G(-vr + wq)])\right). \tag{6}$$

3 Algorithm of Square Root Ensemble Kalman Filter and Particle Filter

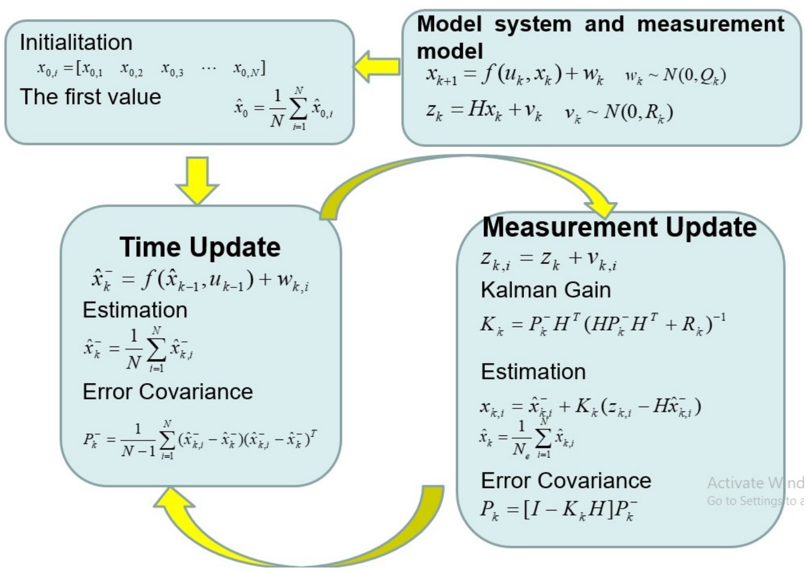

Figure 2: Flowchart of the application of the EnkF-SR algorithm to the dynamic system model [15, 16].

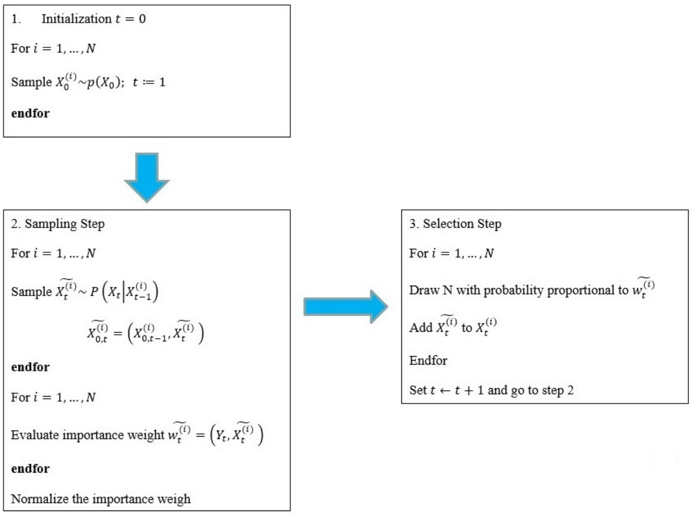

Figure 3: Flowchart of the application of the Particle Filter algorithm to the dynamic system model [17].

4 Simulation Results

The simulation is used and generated 250 and 500 ensembles. The starting point given in each trajectory is x(0)=0, y(0)=0, and z(0)=0. With the trajectories in diving and emerging motions, the position estimation results in the XY, XZ, and XYZ planes by using the EnKF-SR and Particle Filter methods with generation of 250 ensembles were obtained as in Figures 4 and 5. In addition, a table of RMSE values for the EnKF-SR and Particle Filter methods is displayed, in which the EnKF-SR method uses 300 ensembles as shown in Table 2.

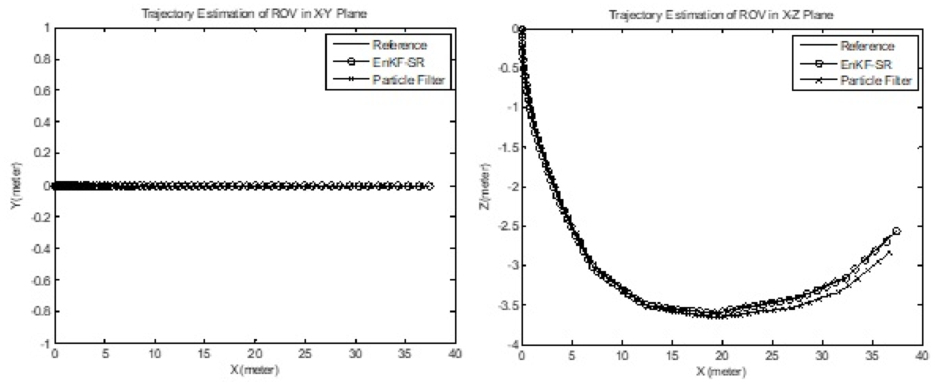

Figure 4: Position Estimation of ROV Diving and Emerging Motions in XY and XZ Planes with 250 ensembles.

Figure 4 shows that the ROV follows the trajectory predetermined in the XY plane and in diving and emerging motions. The error obtained in the simulation by generating 250 ensembles is the X position with the smallest error of 0.08235 m or a position error of 8.2 cm from the target passed, which is 35 m or an error of 0.0023% by the EnKF-SR method, for the Z position, 0.00467 m, there is a position error of 0.47 cm from the target passed, which is 4 m or an error of 0.0011% by the EnKF-SR method. The small position error by the three methods is due to the small RMSE of each DOF. Meanwhile the results by the Particle Filter method produced a position error of 0.1235 m for the X position and 0.00895 m for the Z position.

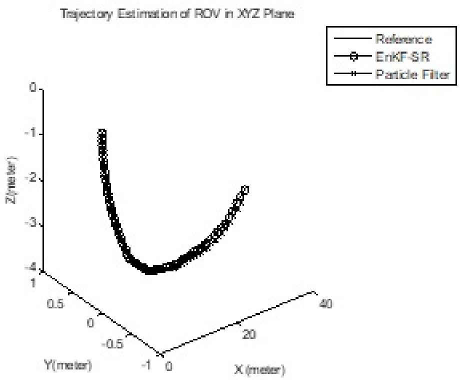

Figure 5: Position Estimation of ROV Diving and Emerging Motions in the XYZ Plane with 250 ensembles.

The trajectory combinations predetermined in the XY and XZ planes are then displayed in the three-dimensional plane as shown in Figure 5. In the XYZ plane, the ROV follows the trajectory where the ROV moves forward and dives then rises upward (emerging) without turning motion. The three methods are very accurate as shown in Table 2 indicating that by the EnKF-SR method, in the X position, the position error is 8.2 cm from the passed target of 35 m or an error of 0.0023% and in the Z position, the position error is 0.47 cm from the passed target of 4 m or an error of 0.0011%, while the Paticle Filter method has an error in the X position of about 0.0035% and that in the Z position of about 0.0022%.

Figure 6 shows that the ROV follows the trajectory predetermined in the XY plane with diving and emerging motions. The error obtained in the simulation by generating 250 ensembles is the X position, the smallest error is 0.06978 m or it has a position error of 6.97 cm from the traversed target of 35 m or an error of 0.0019% by the EnKF-SR method, for the Z position, 0.00359 m, it has a position error of 0.359 cm from the traversed target of 4 m or an error of 0.00089% by the EnKF-SR method. The small position error in the three methods is due to the small RMSE of each DOF. Meanwhile the results by the Particle Filter method produced a position error of 0.1051 m for the X position and 0.00722 m for the Z position.

The XYZ plane is a combination of the trajectories made in the XY and XZ planes and then displayed in the three-dimensional plane as shown in Figure 7. In the XYZ plane, the ROV follows the trajectory where the AUV moves forward, dives, then rises upward (emerging) without turning movement. The three methods are very accurate, shown in Table 2. By the EnKF-SR method, in the X position, the position error is 6.97

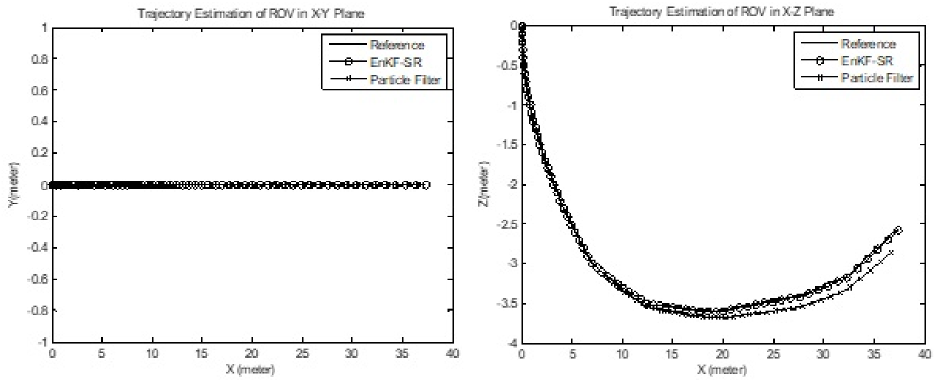

Figure 6: Position Estimation of ROV Diving and Emerging Motion in XY and XZ Planes with 500 ensembles.

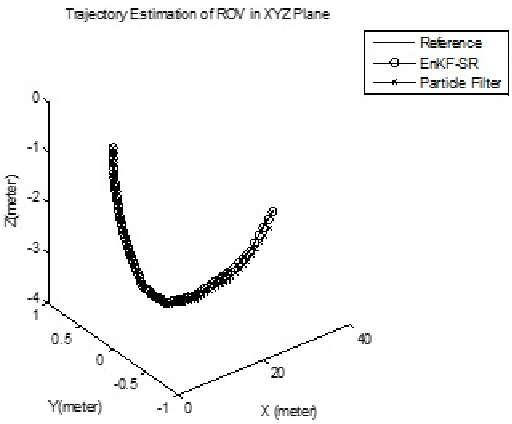

Figure 7: Position Estimation of ROV Diving and Emerging Motions in the XYZ Plane with 500 ensembles.

cm from the target passed, which is 35 m or an error of 0.0019%, and in the Z position, the error is 0.359 cm from the target passed, which is 4 m or it has an error of 0.00089%, while by the Paticle Filter method, in the X position, it has an error of about 0.003% and in the Z position, it has an error of about 0.0018%.

Table 2 shows that by generating 250 and 500 ensembles, the EnKF-SR method has a higher accuracy than the Particle Fililter method for the position in the translational and rotational motion. The EnKF SR method has a more accurate position estimation in the translational and rotational motions than the Particle Filter. This shows that the X position error is affected by the translational and rotational motions in the X axis, that is, surge and roll, while the Z position error is affected by the translational and rotational motions in the Z axis, that is, heave and pitch. Thus, overall the EnKF-SR method has a higher accuracy than the Particle Filter with either 250 ensembles or 500 ensembles. However, both estimation methods can be implemented for the position estimation of the ROV and other autonomous vehicle systems.

	300 ensembles		500 ensembles	
	Particle Filter	EnKF-SR	Particle Filter	EnKF-SR
Position X	0.0035%	0.0023%	0.003%	0.0019%
Position Y	0	0	0	0
Position Z	0.0022%	0.0011%	0.0018%	0.00089%
Simulation Time	9.5114 s	9.8378 s	12.5114 s	12.7624 s

Table 2: Comparison of Errors generated by EnKF-SR and Particle Filter in Diving and Emerging Motions.

5 Conclusion

Based on the results of the discussion and analysis above, by generating 250 and 500 ensembles, the EnKF-SR method is more accurate than the Particle Filter method for the position in translational and rotational motions. The EnKF-SR method has a position error in translational and rotational motions and is more accurate than the Particle Filter. This shows that the X position error is influenced by the translational and rotational motions in the X axis, that is, surge and roll, while the Z position error is influenced by the translational and rotational motions in the Z axis, that is, heave and pitch. In conclusion, overall the EnKF-SR method is more accurate than the Particle Filter one with either 250 ensembles or 350 ensembles. However, both motion estimation methods can be implemented for the position estimation of the ROV and other autonomous vehicle systems.

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