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DIVING MOTION ESTIMATION OF REMOTELY OPERATED VEHICLE USING ENSEMBLE KALMAN FILTER AND H-INFINITY

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ABSTRACT

ROV (Remotely Operated Vehicle) is a product of technological development, functioning to perform tasks in the water. Big tasks such as coral reef exploration, oil refineries, underwater monitoring, and sea accident rescue are carried out by such technology. ROV or unmanned submarines have 6 degrees of freedom, but for diving it requires only 3 movements, that is, surge, heave, and pitch motions. In its operation, the ROV requires a navigation system in the form of estimation of the ROV position under diving conditions. In this study, two methods were used to estimate the ROV position under diving conditions, that is, the H-infinity method and the Ensemble Kalman Filter (EnKF). Both methods proved reliable on other platforms. The simulation results in this study showed that the EnKF method was more accurate than the H-Infinity method. The H-Infinity method had an accuracy of around 87%, while the EnKF method reached an accuracy of 99 %.

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1. INTRODUCTION

ROV (Remotely Operated Vehicle) is a product of technological development, functioning to perform tasks in the water. Big tasks such as coral reef exploration, oil refineries, underwater monitoring, and sea accident rescue accidents are done by such technology. ROV is a robot used in water [1]. To control this robot, the remote was used on the surface. Then the robot is submerged in water and connected, using a cable to transmit data and its energy source. ROV or an unmanned submarine has 6 degrees of freedom driven by the propulsion system that regulates the angular velocity of the AUV and the fin system that regulates the angular position of the fins and rudder [2] [3] [4]

Besides ROV, there is an AUV (Autonomous Underwater Vehicle), which also has almost the same function. For AUV, the control is done automatically. So, in carrying out the mission, the AUV is given a special program to do a certain task, then the robot does it as programmed without being controlled by a pilot/operator [5]. The AUV itself requires batteries to do its job, so it has limited time to accomplish its mission. The advantage of the ROV itself is that it is connected to a data cable and power cable, so the use of an ROV can be very long and maximized [6]. The pilot/operator running the ROV usually uses the camera on the ROV, then any things caught by the camera are displayed on the monitor screen to monitor whatever is seen in the water. On the ROV are embedded various sensors to monitor various indicators its operator wants to know while in the water, such as water density, temperature, current, etc.

This study started with the preparation of an equation of 3-DOF motion model, that is, the motion of surge, heave, and pitch. The surge and heave motions are translational motions on the x-axis and z-axis, while the pitch motion is rotational motion on the z-axis. Then, the position estimation method was applied to determine the ROV movement when diving underwater. Several methods of position estimation or ROV or AUV motion estimation ever applied by previous studies were Fuzzy Kalman Filter [7], Extended Kalman Filter [8] [9], EnKF-SR [10], Unscented Kalman Filter [5], H-Infinity [11] and EnKF [12] [13]. Of the six position estimation methods above, the EnKF and H-Infinity methods were effectively applied to both linear and nonlinear models. And the objective of this study was to estimate the ROV diving motion using the EnKF and H-Infinity methods.

2. RESEARCH METHODS

2.1 Remotely Operated Vehicle (ROV) with 3- DOF

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

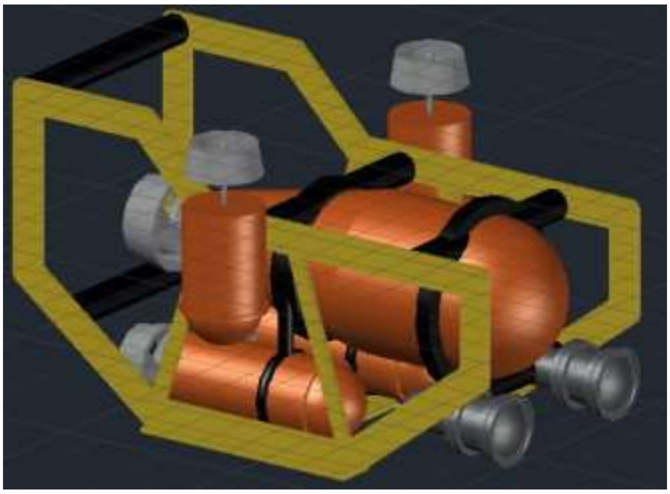

Figure 1. Profile of *Rescue* ROV [5] [6]

Table 1. Specifications of *Rescue* ROV [5] [6]

Weight	15 Kg
Length Overall	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

This study focused on the diving motion only so as to observe just three types of motions, that is, surge, heave, and pittch, of which the motion equations are as follows [14]:

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:

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

2.2 The Ensemble Kalman Filter and H-Infinity Algorithms

In this study, the Ensemble Kalman Filter and H-infinity algorithms were applied to the diving ROV model. The following is an overview of the flowchart of the EnKF and H-Infinity methods.

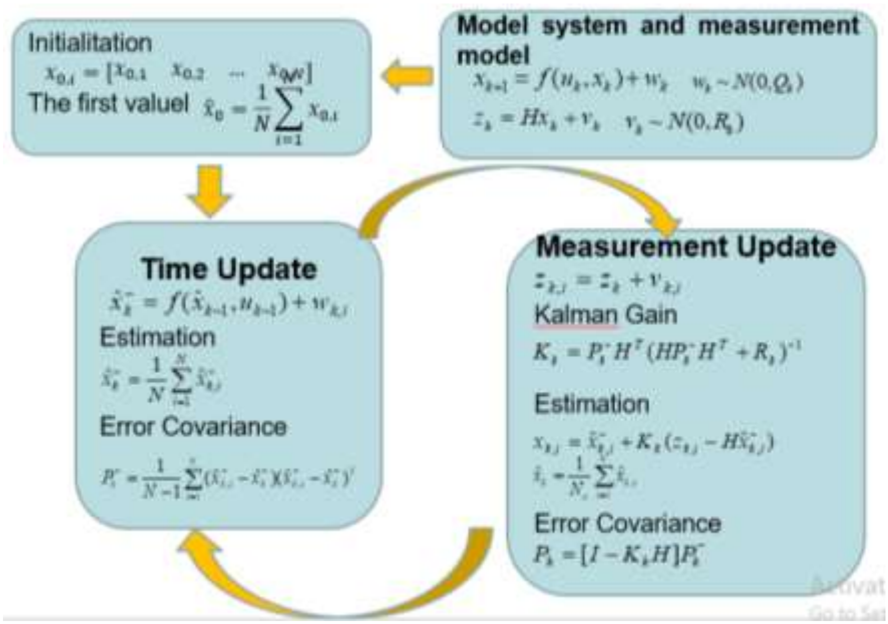

Figure 2. The flowchart of the EnKF algorithm [15] [16]

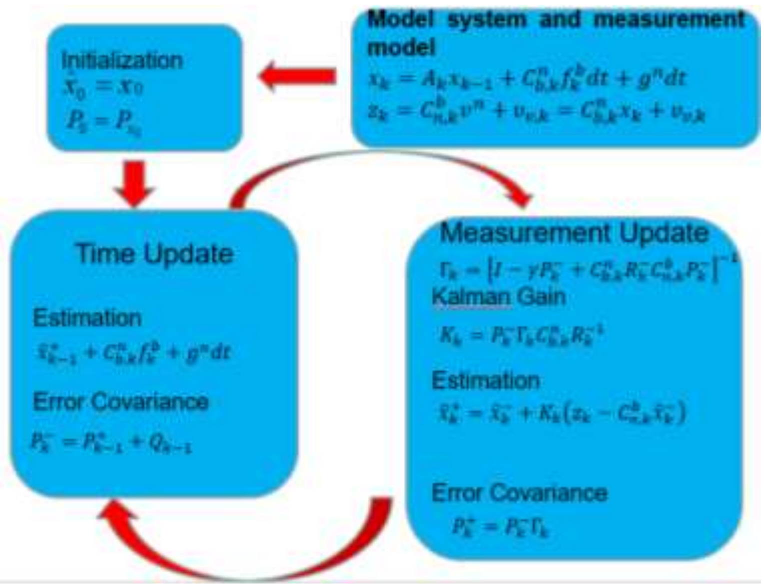

Figure 3. The flowchart of the H-infinity algorithm [17] [18]

3. RESULTS AND DISCUSSION

In this paper, the focus of the study was on diving movements, so it only requires 3-DOF to estimate the diving motion using two methods, that is, the EnKF and H-Infinity methods. The accuracy of the two methods was compared by generating 200 and 300 ensembles. The application of the EnKF and H-infinity algorithms on a discrete model of the 3-DOF model of the ROV diving motion. Figure 4 shows that the EnKF method was able to follow the specified reference value with a very high level of accuracy of around 99%, but the results of the H-infinity algorithm were less accurate and slightly off the mark with an accuracy of about 87%.

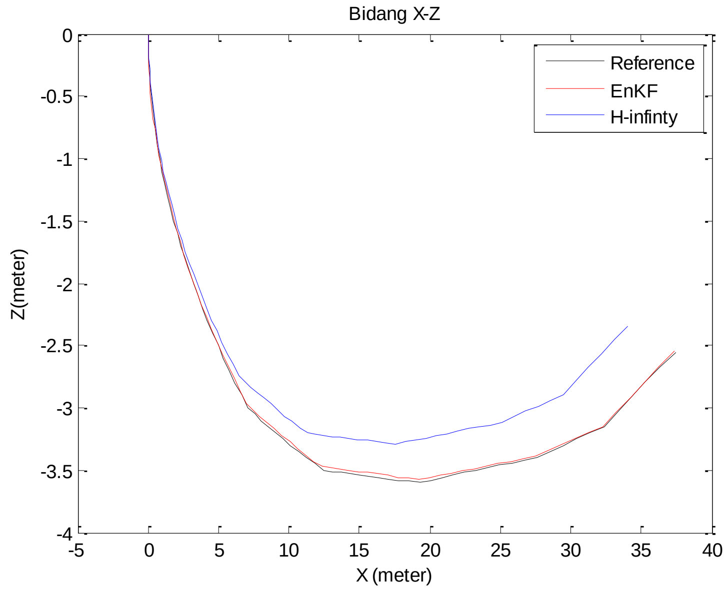

Figure 4. Estimation of ROV diving position using EnKF and H-infinity in XZ Plane with 300 ensembles

In this paper, the focus of the study was on diving movements, so it only requires 3-DOF to estimate the diving motion using two methods, that is, the EnKF and H-Infinity methods. In this paper, the accuracy of the two methods was compared by generating 200 and 300 ensembles. The application of the EnKF and H-infinity algorithms on a discrete model of the 3-DOF model of the ROV diving motion. Figure 4 shows that the EnKF method was able to follow the specified reference value with a very high level of accuracy of around 99%, but the results of the H-infinity algorithm were less accurate and slightly off the mark with an accuracy rate of about 87%.

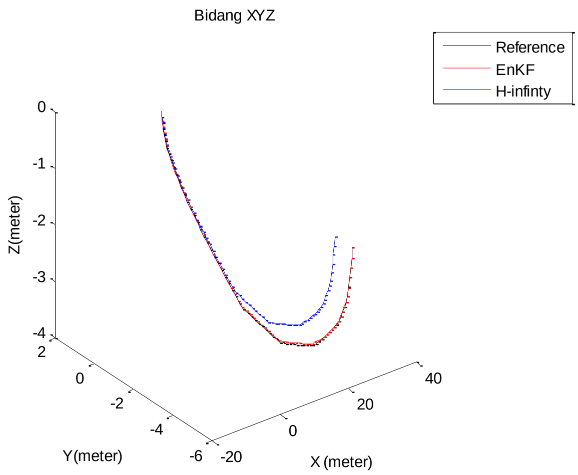

Figure 5. Estimation of ROV diving position using EnKF and H-infinity in XYZ Plane with 300 ensembles

In Table 2, it can be seen that the EnKF method by generating 300 ensembles was more accurate than 200 ensembles. With 300 ensembles it had an accuracy of 99%, while with 200 ensembles, it had an accuracy of only 98%. Likewise, by the H-Infinity method, the accuracy was 87%, in other words, it was 2% better than by using 200 ensembles. In view of the simulation time, it can be seen that with 300 ensembles, it took time much longer than with 200 ensembles due to the much longer computational to process the ensembles.

Table 2. The accuracy rates of the ROV motion by EnKF and H-infinity method

	200 Ensemble		300 Ensemble	
	EnKF	**H-Infinity**	**EnKF**	**H-Infinity**
XZ Motion	98.5 %	85%	99 %	87%
Simulation Time	8.5 s	11.9 s	10,3 s	14,5 s

This study can be used as a reference that the EnKF method was effectively applicable to various models for either linear or nonlinear, and it had small errors in both motion and position estimation. Regarding the H-infinity method, it had a bigger error than the EnKF since the 3-DOF ROV model was quite strong in nonlinear, so it required a more detailed correction. Overall, the two motion and position estimation methods, the EnKF and the H-infinity, can be used as a method of estimating the motion of the ROV for both diving and turning positions.

4. CONCLUSIONS

Based on the results of the two simulations above, it was found that the EnKF method was more accurate than the H-infinity method. The EnKF method by generating 300 ensembles was more accurate than 200 ensembles, in which with 300 ensembles, its accuracy was 99%, while that with 200 ensembles was only 98%. Likewise, by the H-Infinity method, the accuracy was 87%. In other words, it was 2% better than that using 200 ensembles. Overall, the two motion and position estimation methods, the EnKF and the H-infinity, can be used as a method of estimating the motion of the ROV for both diving and turning positions.

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REFERENCES

[1] T. Herlambang, H. Nurhadi and S. Subchan, "Preliminary Numerical Study on Designing Navigation and Stability Control Systems for ITS AUV," *Applied Mechanics and Materials,* vol. 493, pp. 420-425, 2014.

[2] 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,* vol. 9, no. 6, pp. 553-560, 2015.

[3] T. Herlambang, S. Subchan and H. Nurhadi, "Design of Motion Control Using Proportional Integral Derivative for UNUSAITS AUV," *International Review of Mechanical Engineering,* vol. 12, no. 11, pp. 928-938, 2018.

[4] T. Herlambang, D. Rahmalia and T. Yulianto, "Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) for Optimizing PID Parameters on Autonomous Underwater Vehicle (AUV) Control System," in *The Second Internatonal Conference on Combinatorics, Graph Teory and Network Topology*, Jember, Indonesia, 2018.

[5] T. Herlambang, D. Rahmalia, H. Nurhadi, A. Suryowinoto and A. Muhith, "Estimation of Remote Operated Vehicle Motion in XY Plane using Unscented Kalman," in *The 1st International Conference on Neuroscience and Learning Technology*, Jember, Indonesia, 2021.

[6] F. Yudianto, T. Herlambang, F. A. Susanto, A. Suryowinoto and B. P. Tomosouw, "Design of ROV Straight Motion Control Using Proportional Sliding Mode Control Method," *BAREKENG: Jurnal Ilmu Matematika Dan Terapan,* vol. 16, no. 3, 2022.

[7] Z. Ermayanti, E. Apriliani, H. Nurhadi and T. Herlambang, "Estimate and Control Position Autonomous Underwater Vehicle Based on Determined Trajectory using Fuzzy Kalman Filter Method," in *International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation*, Surabaya, 2015.

[8] T. Herlambang, S. Subchan and H. Nurhadi, "Estimation of UNUSAITS AUV Position of Motion Using Extended Kalman Filter (EKF)," in *International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation*, Malang, Indonesia, 2019.

[9] T. Herlambang, D. Adzkiya and H. Nurhadi, "Trajectory Estimation Of Autonomous Surface Vehicle Using Extended Kalman Filter," in *The Third Internatonal Conference on Combinatorics, Graph Teory and Network Topology*, Jember, Indonesia, 2019.

[10] H. Nurhadi, T. Herlambang and D. Adzkiya, "Trajectory Estimation of Autonomous Surface Vehicle using Square Root Ensemble Kalman Filter," in *2019*, Malang, Indonesia, International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation.

[11] T. Herlambang, D. Rahmalia, A. Suryowinoto, F. Yudianto, F. A. Susanto and M. Y. Anshori, "H-infinity for autonomous surface vehicle position estimation," in *The 5th International Conference of Combinatorics, Graph Theory, and Network Topology*, Jember, Indonesia, 2021.

[12] H. Nurhadi, T. Herlambang and D. Adzkiya, "Position Estimation of Touristant ASV Using Ensemble Kalman Filter," in *International Conference on Mechanical Engineering*, Yogyakarta, 2019.

[13] S. Subchan, T. Herlambang and H. Nurhadi, "UNUSAITS AUV Navigation and Guidance System with Nonlinear Modeling Motion using Ensemble Kalman Filter," in *International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation*, Malang, Indonesia, 2019.

[14] H. Nurhadi, T. Herlambang and D. Adzkiya, "Design of Sliding Mode Control for Surge, Heave and Pitch Motion Control of UNUSAITS AUV," in *International Conference on Mechanical Engineering*, Yogyakarta, Indonesia, 2019.

[15] P. katias, D. F. Karya, T. Herlambang and H. Khusnah, "Ensemble Kalman Filter for Crude Oil Price Estimation," in *The Second Internatonal Conference on Combinatorics, Graph Teory and Network Topology*, Jember, INdonesia, 2018.

[16] T. Herlambang, Z. Mufarrikoh, D. F. Karya and D. Rahmalia, "Estimation Of Water Level And Steam Temperature In Steam Drum Boiler Using Ensemble Kalman Filter Square Root (EnKF-SR)," in *The First Internatonal Conference on Combinatorics, Graph Teory and Network Topology*, Jember, Indonesia, 2017.

[17] M. Y. Anshori, T. Herlambang, P. Katias, F. A. Susanto and R. A. Rasyid, "Profitability estimation of XYZ company using H-infinity and Ensemble Kalman Filter," in *The 5th International Conference of Combinatorics, Graph Theory, and Network Topology*, Jember, Indonesia, 2021.

[18] T. Herlambang, A. Muhith, I. Irhamah, M. Y. Anshori, D. Rahmalia and D. K. Karya, "Implementation of H-infinity and Ensemble Kalman Filter for Whole Blood (WB) Estimation in PMI Bojonegoro," in *the 6th National Conference on Mathematics and Mathematics Education*, Semarang, Indonesia, 2021.