Estimation of Linear and Pressure Drag Coefficients of an Underwater Robot Using Nonlinear Kalman Filters

Mohammad Ghazanfari , S. Mohammad Bozorg *

Department of Mechanical Engineering, Yazd University, Yazd, Iran

Abstract

Using kinetic models for the navigation of underwater robots is an important issue that has recently attracted the attention of many researchers. They are used as an auxiliary tool alongside the common navigation algorithms that use the kinematic models of the robots. Their use in underwater navigation is more crucial as the GPS and radio signals are not available in underwater environments and navigation algorithms mainly rely on the kinematic models used in a dead-reckoning configuration, where IMU and/or DVL data are used. To use a kinetic model for the navigation of an underwater vehicle, it is required to have accurate values of its hydrodynamic coefficients, where the linear and pressure drag coefficients are among the most crucial parameters to be identified. In this paper, the drag coefficients of a sample remotely operated vehicle (ROV) are estimated using Extended Kalman filter (EKF) and Unscented Kalman filter (UKF). For this purpose, a six DOF model of the underwater vehicle is used to simulate its motion. Then, the inputs and outputs of the simulated model are imported into the estimation algorithms to identify the drag coefficients of the robot. The simulation results show that the UKF identifies the hydrodynamic coefficients more accurately than EKF, using the same model and measurement noises. Also, by comparing the simulated maneuvers of the robot using the identified coefficients and the exact coefficients of the robot, it is observed that the coefficients identified by UKF lead to more accurate trajectories as compared to the coefficients identified by EKF.

Keywords

Parameters Estimation, Linear and Pressure Drag Coefficients, Unscented Kalman Filter, Extended Kalman Filter, Remotely Operated Vehicle

* Corresponding Author: Email: bozorg@yazd.ac.ir

1. **Introduction**

The use of a kinetic model for an underwater robot is crucial for simulation of the robot motions and maneuvers. It can also be used in the navigation algorithms to enhance the estimates of the robot's position and velocity. To develop a kinetic model for an underwater vehicle, several approaches can be taken. A common method is to derive the equations of motion using Newton-Euler or Lagrange equations. The forces and torques that appear in these equations are commonly expressed in terms of hydrodynamic coefficients of the robot in different modes of movements. To evaluate these coefficients, several methods are available: i) experimental methods using prototypes of the robot tested in water or air tunnels, ii) computational fluid dynamic (CFD) methods based on the geometry of the vehicle simulated in an incompressible fluid environment, iii) system identification methods using the data obtained from the vehicle actuators and sensors respectively as the input and output of the kinetic model. In this paper, the latter approach is taken and Kalman Filter is used as the identification tool.

In most previous researches, in order to estimate the position and velocity of underwater robots, the data of sensors such as inertial measurement units (IMU) are used in kinematic models of Kalman filters and magnetometers, tilt-meters and pressure sensors are used as external measurements. In the case of accumulation of navigation errors and also when some sensors fail to perform properly, using kinetic model of the robot helps to improve the accuracy of the navigation [1]. The accuracy of the values of the hydrodynamic coefficients of the robot used in the dynamic model is crucial in such navigation algorithms. In some previous works, the dynamic of the robot is modeled as decoupled modes of motion [2]. Thence, the interaction between the different modes is ignored, which in turn, results in impairing the accuracy of the navigation [3].

In this paper, the hydrodynamic coefficients of a sample underwater robot including its linear and pressure drag coefficients are estimated using EKF and UKF. A six-degree of freedom kinetic model of an underwater robot adopted from [4] is used as the kinetic model of the system and the hydrodynamic coefficients are identified without decoupling the motions in different modes, in contrary to the previous works such as [2]. While related works are presented in [5] and [6], in this work, a complete comparison of the estimation results including the covariance of estimated parameters are presented. Also, the real trajectories of the robot and the trajectories that are obtained from the simulation of the robot with the identified values of the hydrodynamic coefficients are compared.

2. **Methodology**

The equations of motions of a sample underwater robot are adopted from [4] as:

$$F_1 = \begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = (M_{RB} + M_A)^{-1}(C_D - C_A - C_{RB}) \begin{bmatrix} u \\ v \\ w \\ p \\ q \\ r \end{bmatrix} + F_{restoring} + F_{thrust} + F_{cable}$$

$$F_2 = \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = T(\phi, \theta, \psi) \begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix}.$$

The position and velocity states (Figure 1), the robot parameters, the actuating forces acting on the robot and their nominal values are defined in the paper. The robot is an ROV and is operated and communicated via a cable, but the dynamic of the cable is not included in system equations due to the complexity of its modeling.

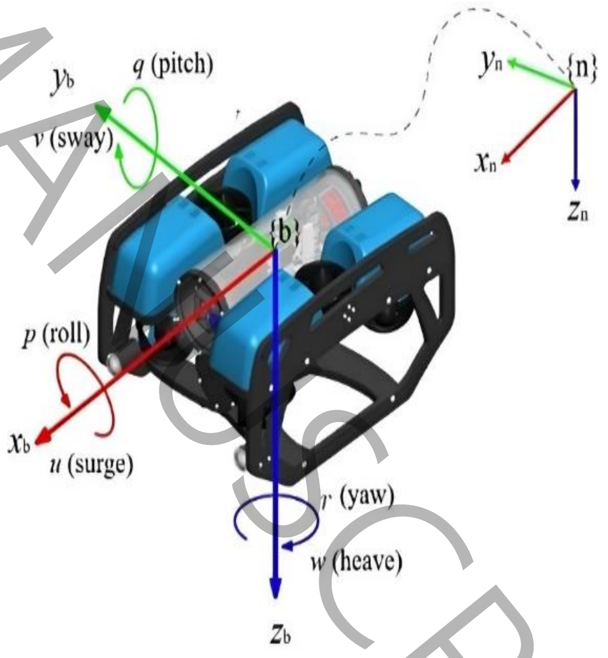

Figure 1. Boby and inertial navigation coordinates

The details of the implementation of EKF and UKF algorithms are presented in the paper. The hydrodynamic coefficients are added as auxiliary states of the system, as extra states to be identified.

3. **Results**

The output of the 6-DOF simulation of the robot motion under the various thruster inputs are used in the identification process using the EKF and UKF as nonlinear estimators. In particular, identification of the hydrodynamic coefficients of robot is performed. The numerical values of the covariance of process and measurement noises are given. A comparison of the accuracy of the two filters in estimating the hydrodynamic coefficients is presented in Table 1. The covariances of these estimates are also discussed in the paper.

Table 1. Comparison of the estimates of the suggested algorithms

		Estimates		Percent Error	
Coef.	Unit	EKF	UKF	EKF	UKF
X_u	N.s/m	4.76	4.4	18.1	9.1
Y_v	N.s/m	5.86	6.34	5.8	2
Z_w	N.s/m	4.86	5.35	6.1	3.2
K_p	N.s/rad	0.04	0.05	42	10
M_q	N.s/rad	0.08	0.09	21	32
N_r	N.s/rad	0.10	0.08	50	15
$X_{u\|u\|}$	$N.s^2/m^2$	17.72	18.78	2.5	3.3
$Y_{v\|v\|}$	$N.s^2/m^2$	20.45	21.8	5.5	0.6
$Z_{w\|w\|}$	$N.s^2/m^2$	41.93	38.15	13	4
$K_{p\|p\|}$	$N.s^2/rad^2$	1.19	1.6	23	3.2
$M_{q\|q\|}$	$N.s^2/rad^2$	1.48	1.35	4.5	13
$N_{r\|r\|}$	$N.s^2/rad^2$	1.21	1.83	22	18

4. **Conclusions**

The results in Table 2 show that the estimates of UKF are closer to the real values of the hydrodynamic coefficients than EKF estimates, in overall. The motion of the robot is also simulated using these identified values and the trajectories are compared with the known trajectory of the robot. It is observed the trajectory resulted from UKF identified parameters are closer to the actual trajectory of the robot.

5. **References**

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