Applied Ocean Research 54 (2016) 67–72

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Robust ROV path following considering disturbance and measurement error using data fusion

M. Hosseini, S. Seyedtabaii*

Electrical Engineering Department, Shahed University, Tehran, Iran

ARTICLE INFO

Article history:
Received 8 June 2015
Received in revised form 6 September 2015
Accepted 29 October 2015
Available online 7 December 2015

Keywords:
ROV control
High order sliding mode
INS
EKF
2nd order sliding mode

ABSTRACT

ROV accurate path following is challenging due to system unmodeled dynamics, disturbances and navigation sensors error. The model uncertainty and disturbances are commonly treated using robust methods such as the sliding mode controller where by incorporating an integral action in the zero tracking error is also guaranteed. Practically, the ROV position data is often computed using low cost inertial measurement unit (IMU) with outputs contaminated with bias and noise. Failure of mission is an immediate consequence of employing such biased sensors. However, the problem can be circumvented using the concept of redundant measurements and data fusion. In this respect, a set of 12 measurements from IMU, magnetometer and Doppler velocity log (DVL) are employed where the last two are aided sensors. The set up is shown to be capable of providing ROV path following with zero (in average) steady state tracking error irrespective of its dynamic parameters, environmental disturbances and erroneous data; as if it enjoys the exact values of the position of the ROV. It means that the combined DVL and magnetometer are sufficient for filtering the IMU biased measurements. Various simulations conducted confirm the results.
© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Remotely operated vehicles (ROVs) play a crucial role in underwater oil and gas extraction, exploration, salvage and monitoring operations [1]. ROV is generally guided by a human pilot through a link cord providing its power and data communication. However, nowadays the demand for an autonomous system is growing due to its lower operation cost compared with manned vessels.

Accurate accomplishment of tasks such as path tracking, dynamic positioning (or station keeping), auto-heading and auto-depth tuning requires feedback control. ROV control, however, faces three major challenges: (1) there are parametric uncertainties in the vehicle model due to the added mass, hydrodynamic coefficients and so on that is also increased as the vehicle undertakes mechanical operations. (2) The sensors measuring states suffer from errors due to the bias, drift and noises (3) Vehicles are usually exposed to the highly dynamic underwater current and waves, which inflect significant disturbances to their missions.

In practice, most of industrial underwater robots use Proportional Integral Derivative (PID) controller due to its simplicities. An example of PID control of ROV has been reported in [1]. However, precise task execution requires sophisticated measures and provisions to cope with system nonlinearities, disturbances and measurement errors. In this respect, employing adaptive methods have been reported in [2,3]. Using fuzzy technique is the subject of study in [4].

It is well understood that unmodeled dynamics and disturbances can be efficiently managed using sliding mode control (SMC). It is studied for ROV path tracking in [1,5]. Adaptive SMC has also been tried in [2]. In [6] a Model-Free High Order Sliding Mode Control is suggested. Adaptive neuro-fuzzy sliding mode algorithm is another scheme for accurate achievement of the tasks that has been suggested in [7]. Application of adaptive fuzzy sliding mode is also detailed in [8].

Apart from the control strategy, accurate path following requires clean measured ROV position. In real world, direct ROV position measurement is not economically sound; rather it is calculated using output of low cost sensors such as Inertial Measurement Unit (IMU). Unfortunately, the sensor output is contaminated with bias and noise, which ends up in wrong position estimation. To compensate for the errors, some auxiliary gauges are needed to provide measurement redundancy. Doppler velocity logger (DVL), magnetic compass, depth sensor, inclinometer, acoustic based sensors are those that are usually used [9]. The redundant measurements are fused together using Kalman filter to provide accurate ROV position estimate.

In this study, a 2nd order SMC is used for ROV path following. The ROV position measurement is estimated using IMU (3 accelerometers and 3 rate gyros), a 3-axis compass and a three axis Doppler velocity unit. The Measurement error is filtered using Extended Kalman. It is shown that in spite of the measurement

* Corresponding author. Tel.: +98 2151212080.
E-mail addresses: seied64@yahoo.com (M. Hosseini), stabaii@shahed.ac.ir (S. Seyedtabaii).

0141-1187/$ – see front matter © 2015 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apor.2015.10.009

error, underwater current disturbances and the model uncertainties, the control system achieves zero (in average) steady state tracking error.

In Section 2, the dynamical model of ROV is briefly described. The modified 2nd order SMC concept is described in Section 3. The navigation apparatuses and filtering scheme is introduced in Section 4. Simulation results are illustrated in Section 5 and lastly conclusion comes in Section 6.

2. System description

A typical ROV has been depicted in Fig. 1. It has 4 thrusters. T_{x1} and T_{x2} administer the surge movement, the sway motion is accelerated by T_y, T_z manages the heave operation and yaw rotation is performed by $T_{x1}-T_{x2}$. The strongly nonlinear, coupled, time-varying, and uncertain in parameters dynamic model of ROV with respect to the local body-fixed reference frame, in matrix form, is given by [6],

$$M_R\dot{X}_b + C(X_b)X_b + D(X_b)X_b + g(X_E) = F + F_d$$
$$F = [X\,Y\,Z\,K\,M\,N]^{\mathrm{T}} \qquad (1)$$
$$X_b = [u\,v\,w\,p\,q\,r]^{\mathrm{T}}$$

The Body-fixed frame is attached to the vehicle and its origin is normally located at the center of gravity. In (1), X_b is the body frame state vector containing linear (surge, sway and heave) velocities and angular (roll, pitch and yaw) rates shown in Fig. 1. F is the vector of forces and torques generated by the thrusters and F_d is a vector expressing the environment disturbances.

The other parameters M_R, $C(X_b)$, $D(X_b)$ and $g(X_E)$ are defined as below,

$$M_R = \mathrm{diag}\begin{bmatrix} m - X_{\dot{u}} \\ m - Y_{\dot{v}} \\ m - Z_{\dot{w}} \\ I_{xx} - K_{\dot{p}} \\ I_{yy} - M_{\dot{q}} \\ I_{zz} - N_{\dot{r}} \end{bmatrix} \quad D(X_b) = -\mathrm{diag}\begin{bmatrix} X_u + X_{u|u|}|u| \\ Y_v + Y_{v|v|}|v| \\ Z_w + Z_{w|w|}|w| \\ K_p + K_{p|p|}|p| \\ M_q + M_{q|q|}|q| \\ N_r + N_{r|r|}|r| \end{bmatrix}$$

$$C(X_b) = \begin{bmatrix} 0 & 0 & 0 & 0 & (m - Z_{\dot{w}})w & (Y_{\dot{v}} - m)v \\ 0 & 0 & 0 & (Z_{\dot{w}} - m)w & 0 & (m - X_{\dot{u}})u \\ 0 & 0 & 0 & (m - Y_{\dot{v}})v & (X_{\dot{u}} - m)u & 0 \\ 0 & (m - Z_{\dot{w}})w & (Y_{\dot{v}} - m)v & 0 & (m - X_{\dot{u}})u & (M_{\dot{q}} - I_{yy})q \\ (Z_{\dot{w}} - m)w & 0 & (m - X_{\dot{u}})u & (N_{\dot{r}} - I_{zz})r & 0 & (I_{yy} - M_{\dot{q}})q \\ (m - Y_{\dot{v}})v & (X_{\dot{u}} - m)u & 0 & (I_{yy} - M_{\dot{q}})q & (K_{\dot{p}} - I_{xx})p & 0 \end{bmatrix}$$

$$g(X_E) = \begin{bmatrix} 0 \\ 0 \\ 0 \\ -(y_G - y_B)\cos\theta\cos\varphi + (z_G - z_B)\cos\theta\cos\varphi \\ (z_G - z_B)\sin\theta + (x_G - x_B)\cos\theta\cos\varphi \\ -(x_G - x_B)\cos\theta\cos\varphi - (y_G - y_B)\sin\theta \end{bmatrix} mgx$$

On the other hand, the vector $X_E = [x, y, z.\ \phi, \theta, \psi]$ describes the Earth frame state variables: the vehicle x, y and z position and roll, pitch and yaw angles. The relation between speed in the body and Earth frames is expressed by,

$$\dot{X}_E = J(X_E)X_b$$

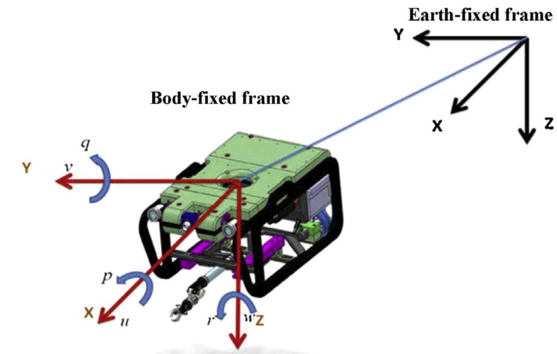

Fig. 1. Body and Earth frames coordinates of an underwater vehicle [6].

where $J(X_E)$ is the transformation matrix converting variables from the body fixed frame to the Earth-fixed frame. Therefore, the model of the system in the earth frame is derived as follows [6]:

$$M_{X_E}(X_E)\ddot{X}_E + C_{X_E}(X_E, X_b)\dot{X}_E + D_{X_E}(X_E, X_b)\dot{X}_E + g_{X_E}(X_E) = F_{X_E} \qquad (2)$$

With

$$M_{X_E} = J^{-T}(X_E)MJ^{-1}(X_E)$$
$$C_{X_E}(X_E, X_b) = J^{-T}(X_E)[C(X_b) - MJ^{-1}(X_E)\dot{J}(X_E)]J^{-1}(X_E)$$
$$D_{X_E}(X_E, X_b) = J^{-T}(X_E)D(X_b)J^{-1}(X_E)$$
$$g_{X_E}(X_E) = J^{-T}(X_E)g(X_E)$$
$$F_{X_E}(X_E) = J^{-T}(X_E)F$$

The hydrodynamic model (2) in the state space form is given by,

$$\dot{X}_E = f(X_E, F_{X_E}, t) + F_d$$

where $f(.)$ a nonlinear function of the states and d is the disturbance vector.

3. Model-free high order sliding mode control

It is difficult to obtain the exact values of hydrodynamic coefficients and disturbances generated by the currents and waves in (2). Therefore, control of ROV requires employing robust methods. Sliding mode control is one of such strategies that can take care of model uncertainties and disturbances. Design of SMC for ROV path following has been investigated in [1]. The conventional sliding mode control is defined by the following equations,

$$s = \dot{e} + \lambda e \qquad e = X_E - X_{Ed}$$

where $s \in R^6$ is the sliding surface, λ is a positive constant, X_E is the current path of ROV, X_{Ed} is the desired path and e is the tracking error. The sliding mode command forcing ROV toward the marked path is expressed by [1],

$$F = F_0 + K\,sgn(s)$$

where F_0 is the nominal control and K is a diagonal 6*6 positive constant matrix. The command manages ROV toward the given path, however, high frequency chattering is also recorded [1].

In [6] a model-free high order sliding mode controller is proposed for reducing the chattering by introducing an integral action in the control command given by,

$$F_{X_E} = -K_d s_r = -K_d\left[s + K_i\int_0^t sgn(s)d\sigma\right] \qquad (3)$$
$$s = \dot{e} + \alpha e - s_d \qquad e = X_E - X_{Ed} \qquad s_d = s(t_0)e^{-kt}$$

Download English Version:

https://daneshyari.com/en/article/1719864

Download Persian Version:

https://daneshyari.com/article/1719864

Daneshyari.com