Navigation of a Remotely Operated Underwater Vehicle Using a Hydrodynamic Model

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Main idea

Navigation of Remotely Operated Vehicles (ROV) is usually based on on-board Inertial Navigation Systems (INS), since external underwater reference systems are not available. A small ROV needs to be light and cheap which rules out the use of a high grade INS. Instead, we suggest using a hydrodynamic model of the ROV for short term navigation and sensor fault diagnostics.

System Overview

The Saab Seaeye Falcon propulsion system consists of five brushless thrusters, four horizontal thrusters for motion in surge, sway and yaw and a thruster for motion in heave. In the experiments the Falcon was equipped with an IMU and a magnetometer of low cost and it also has a doppler velocity log (DVL), measuring the linear velocities, and a depth sensor. The Falcon can also carry other payloads such as camera, sonar, manipulator, and more.

Models

The kinematics is expressed in the commonly used SNAME notation. The ROV is a rigid body and its position and orientation can be described using seven coordinates

$$\boldsymbol{\eta} = \left[x\ y\ z\ \boldsymbol{q}^T\right]^T, \tag{1}$$

where x, y and z denote the position expressed in an inertial frame and $\boldsymbol{q}$ is a unit quaternion, parametrizing the orientation. The velocities

$$\boldsymbol{\nu} = \left[u\ v\ w\ p\ q\ r\right]^T, \tag{2}$$

are expressed in the body fixed frame b. Here, u, v and w denote the velocity in surge, sway and heave and p, q and r denote the angular velocities in roll, pitch and yaw, respectively.

The hydrodynamic model of the ROV is

$$\begin{bmatrix}\dot{\boldsymbol{\eta}}\\ \dot{\boldsymbol{\nu}}\end{bmatrix} = \begin{bmatrix}\boldsymbol{J}(\boldsymbol{\eta})\boldsymbol{\nu}\\ \boldsymbol{M}^{-1}\left(\boldsymbol{\tau} - \boldsymbol{C}(\boldsymbol{\nu})\boldsymbol{\nu} - \boldsymbol{D}(\boldsymbol{\nu})\boldsymbol{\nu} - \boldsymbol{g}(\boldsymbol{\eta})\right)\end{bmatrix} + \begin{bmatrix}\boldsymbol{0}\\ \boldsymbol{I}\end{bmatrix}\boldsymbol{w}, \tag{3}$$

where $\boldsymbol{J}(\boldsymbol{\eta})$ is the transformation from the body fixed frame to the inertial frame, $\boldsymbol{M}$ is the inertia matrix (including added mass), $\boldsymbol{\tau}$ are the thruster inputs, $\boldsymbol{C}(\boldsymbol{\nu})$ is the Coriolis and centripetal matrix, $\boldsymbol{D}(\boldsymbol{\nu})$ is the hydrodynamic damping matrix, $\boldsymbol{g}(\boldsymbol{\eta})$ is the hydrostatic restoring force vector and $\boldsymbol{w}$ is the vector of environment disturbances, respectively.

Previous work [2] has suggested a model for the thruster, according to

$$\boldsymbol{\tau}_{1,T,i} = \left(2.98 \cdot 10^{-4} u_i^3 - 0.016|u_i|u_i + 0.32u_i\right)\boldsymbol{v}_i, \tag{4}$$

where $\boldsymbol{\tau}_{1,T,i}$ is the force from thruster $i = 1, 2 \ldots, 5$ and u_i is the measured input signal for thruster i and $\boldsymbol{v}_i$ is a unit vector pointing in the direction of the thruster force. This model was also used in [1] for position estimation.

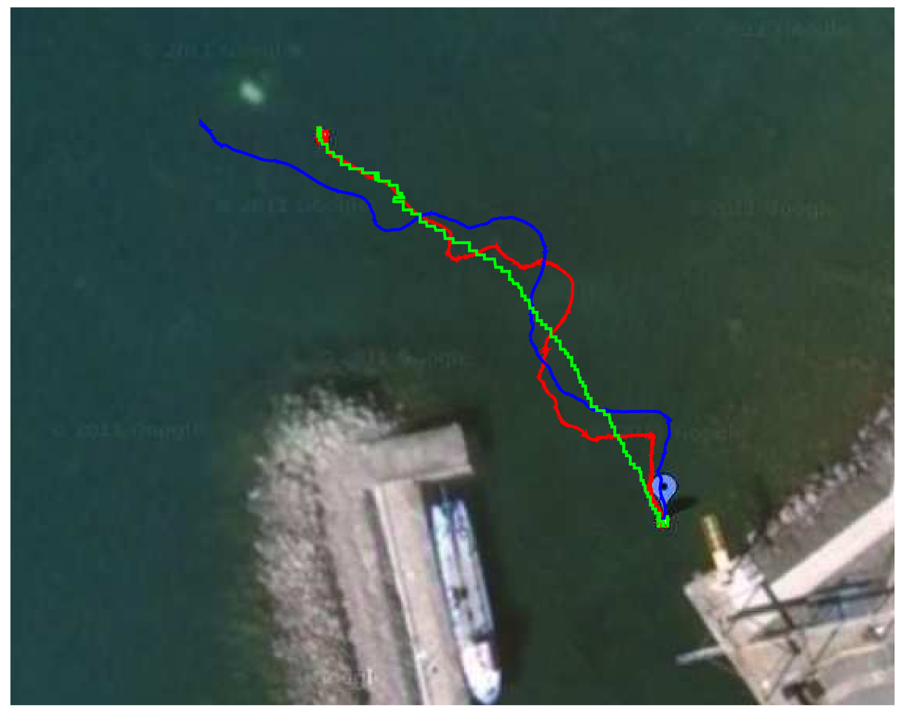
The sensors are modeled as

$$y = h(\boldsymbol{x}) + \boldsymbol{e}, \tag{5}$$

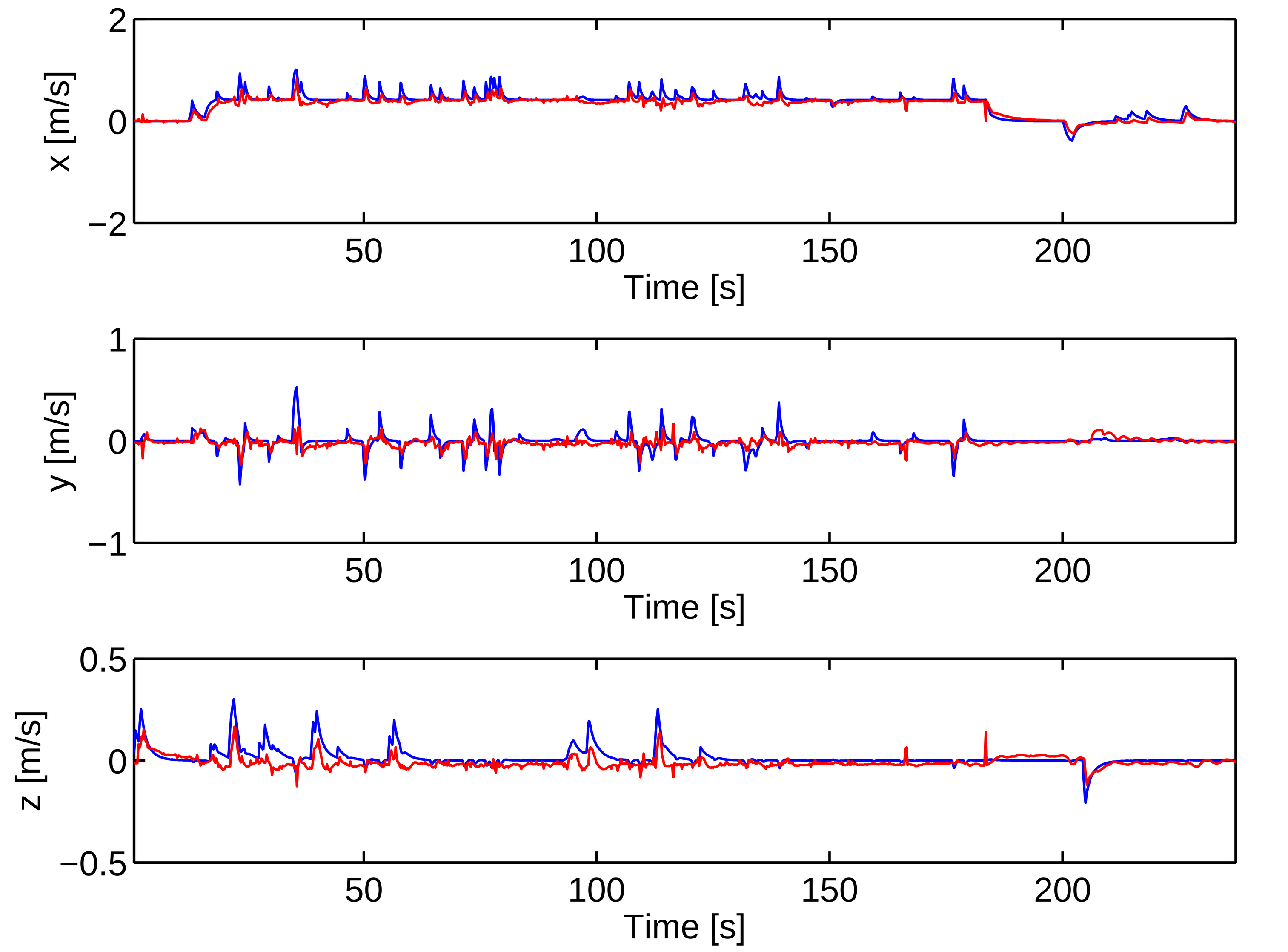
where $h(\cdot)$ is a nonlinear function of the state $\boldsymbol{x}$ and $\boldsymbol{e}$ is Gaussian noise.

Experimental Results

Data was collected in Lake Vättern, Sweden, by following a path which was marked by a cable. The states are estimated using an Extended Kalman Filter (EKF) employing the hydrodynamic model (3) and the sensors modeled as (5). The figure shows an aerial view the estimated trajectory using the hydrodynamics and the sensors in blue, without using the DVL. Using the DVL results in the blue trajectory. The green curve is the reference trajectory which marks the cable.



The speed measured by the DVL in red compared to using the hydrodynamic model (3) in blue.



The linear velocities predicted using the hydrodynamic model are slightly overestimated. Some artifacts may possibly be explained by currents and turbulence not accounted for in the model, also there is noise in the DVL measurements.

Conclusions

It is possible to use the hydrodynamic model for navigation aiding the sensors and this information could also be used to monitor sensor failure. If the surrounding water speed was known a more accurate speed could be predicted.

References

[1] Kenny Jönsson. Position Estimation of Remotely Operated Underwater Vehicle. Master's thesis, Linköping University, 2010.

[2] Carl Millert and Soma Tayamon. Method development for identification of coefficients in a Remotly Operated Vehicle simulator. Master's thesis, Faculty of Science and Technology, Uppsala University, April 2009.