Remote control and path following algorithms for ROV Neptunus and Cybership Enterprise I

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Introduction

The idea of remote control and monitor the behavior of a marine vehicle is in many cases desirable, due to *dirty*, *dangerous*, *distant*, and *dull* operations for humans. In this master thesis, a remote control solution for two marine vehicles, the ROV *Neptunus* and *Cybership Enterprise I* (CSEI) have been developed. The task of the vehicles is to perform path following, where the response can be controlled and monitored remotely. Since full-lab functionality of Neptunus is still not available, CSEI will be the test platform.

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Main Contributions

1. Establishment of a mathematical model of Neptunus.
2. A system identification for Neptunus, considering full scale tests, computer analysis and empirical expressions.
3. Development of a device that allows safe remote control and monitoring of CSEI, using tablet.
4. Guidance and control algorithms for Neptunus and CSEI that perform path following for pre-defined paths. The control systems include integral action to compensate for ocean current.
5. A Nomoto model of CSEI, where the Voith-Schneider propellers are mapped into a rudder-propeller system.
6. Simulation of the control systems using a set of benchmark tests.
7. HIL-test results for CSEI, which evaluate the performance of the path following control systems in a real time environment.
8. Model-scale tests of the motion control systems on CSEI in the MC-lab, where control and monitoring is performed using the tablet.

Mathematical Section

The mathematical model of Neptunus and CSEI has been established using Fossen's robot-like vectorial model for a marine craft.

$$\dot{\boldsymbol{\eta}} = \boldsymbol{J}_{\Theta}(\boldsymbol{\eta})\boldsymbol{\nu}_r \tag{1}$$

$$\boldsymbol{M}_{RB}\dot{\boldsymbol{\nu}}_r + \boldsymbol{C}_{RB}(\boldsymbol{\nu}_r)\boldsymbol{\nu}_r + \boldsymbol{M}_A\dot{\boldsymbol{\nu}}_r + \boldsymbol{C}_A(\boldsymbol{\nu}_r)\boldsymbol{\nu}_r + \boldsymbol{D}(\boldsymbol{\nu}_r)\boldsymbol{\nu}_r + \boldsymbol{g}(\boldsymbol{\eta}) = \boldsymbol{\tau} + \boldsymbol{\tau}_{um} \tag{2}$$

For the path following control systems, only the horizontal plane is considered, i.e a 3 DOF model is set up. A total of three control systems are set up, where the accompanying control laws are;

Heading on WP:

$$\tau_u = -K_p\tilde{u} - K_i\int_0^t \tilde{u}(\tau)d\tau \tag{3}$$

$$\tau_\psi = -K_p\tilde{\psi} - K_i\int_0^t \tilde{\psi}(\tau)d\tau \tag{4}$$

$$\psi_d = \text{atan2}\left(\frac{y_i - y(t)}{x_i - x(t)}\right) \tag{5}$$

where $\tilde{u} = u$ - u_d, and $\tilde{\psi} = \psi$ - ψ_d.

Lookahead based line of sight: Same control law as in (3)-(4), but where

$$\psi_d = \text{atan2}\left(\frac{y_{i+1} - y_i}{x_{i+1} - x_i}\right) + \text{atan}\left(\frac{-e}{\Delta}\right) - \beta_r \tag{6}$$

e is the cross-track error, Δ is the lookahead distance, and β_r is the sideslip angle.

Maneuvering by backstepping control design

$$\boldsymbol{\tau} = -\boldsymbol{z}_1 + \boldsymbol{K}_d\boldsymbol{z}_2 + \boldsymbol{D}(\boldsymbol{\nu})\boldsymbol{\nu} + \boldsymbol{C}(\boldsymbol{\nu})\boldsymbol{\nu} + \boldsymbol{M}\boldsymbol{\sigma} + \boldsymbol{M}\boldsymbol{\chi}v_s(s) - \boldsymbol{K}_I\boldsymbol{\xi} \tag{7}$$

$$\dot{s} = v_s(s) \tag{8}$$

$\boldsymbol{z}_1$, $\boldsymbol{z}_2$, $\boldsymbol{\xi} \in \mathbb{R}^3$ are the error states in position, velocity and integral action, respectively. (8) is the solution of the dynamic task, i.e hold the desired speed along the path.

Methodology

The parameters in the mathematical model of Neptunus have been established using full scale experiments, computer analysis, and estimation theory from the literature. The added mass forces have been calculated using analysis from HydroD, where potential theory have been applied. The linear and quadratic forces have been established from towing tests in the MC-lab.

A custom device that enables real-time communication with CSEI, and Data Dashboard application on a tablet have been developed using the *LabView/VeriStand* framework, where *shared variables* defined as various data types.

The path following control systems for Neptunus and CSEI have been tested using simulations in *MATLAB/Simulink*. Furthermore, HIL-testing have been performed for CSEI, before model-scale testing in the MC-lab. The performance and validity of the control systems have also been concluded using mathematical analysis.

Results

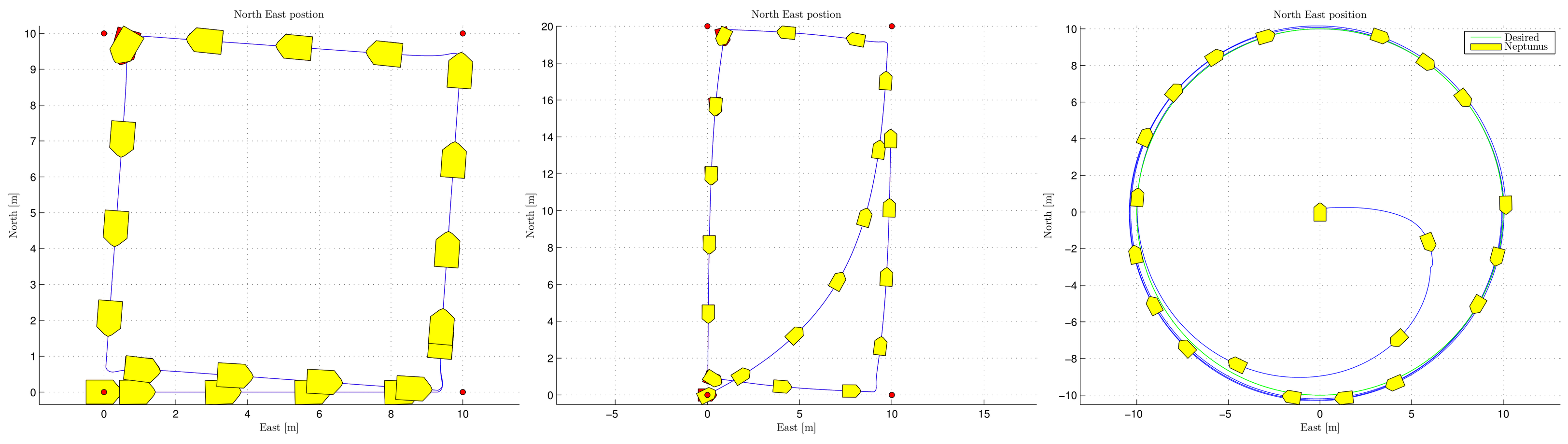
System Identification: The towing tests were performed in translational and rotational DOF, and the drag parameters related to linear and quadratic damping are provided in Table 1.

Linear	Quadratic
X_u = - 2.291	$X_{u\|u\|}$ = -4.008
Y_v = - 4.980	$Y_{v\|v\|}$ = - 35.216
Z_w = - 15.190	$Z_{w\|w\|}$ = -10.304
K_p = - 0.009	$K_{p\|p\|}$ = - 0.191
M_q = 0.050	$M_{q\|q\|}$ = 0.480
N_r = - 0.261	$N_{r\|r\|}$ = - 0.320

Table 1: Drag parameters for Neptunus.

The obtained damping forces, together with the resulting added mass forces, rigid body, and restoring forces gave a satisfying behavior of Neptunus, in compliance with full scale considerations. Especially, the ROV was proven to be passively stable, i.e self-stabilizing in roll and pitch. Moreover, even though it's underactuated (no lateral thruster), Neptunus shows proper turning capabilities, in addition to low drag in surge.

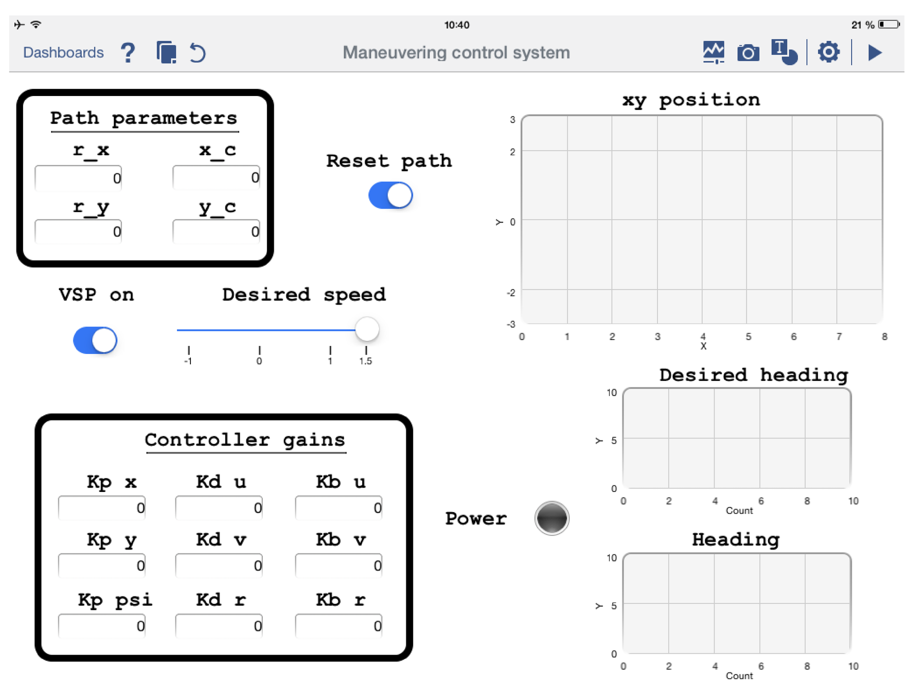
Path following control systems: The obtained simulation model of Neptunus is further used to develop path following control systems on. Neptunus can be treated as a 3 DOF model (surge, sway, and yaw) due to passive stability. In Figure 1, the response for the three control systems are presented.



(a) Heading on WP (b) Lookahead-based LOS (c) DP Maneuvering

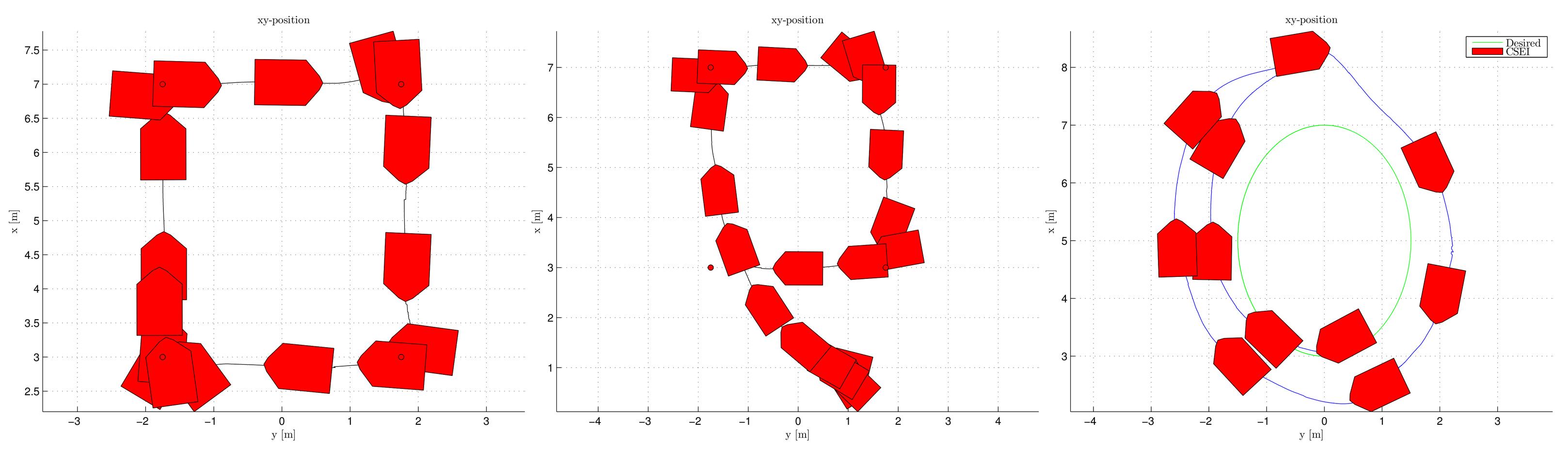
Figure 1: Overview of response in North-East of Neptunus for the various control systems (simulation study).

The same cases have been simulated for CSEI, and the same tendencies were registered. For further validation, HIL and model-scale tests were performed. In Figure 3, model-scale tests of CSEI in the MC-lab are performed. Controller gains were tuned online using the tablet application, see Figure 2a.



(a) iPad user interface (b) QR-code

Figure 2: User interface maneuvering control system.



(a) Heading on WP (b) Lookahead-based LOS (c) Backstepping maneuvering

Figure 3: Overview of response in xy of CSEI for the various control systems (model-scale study).

Conclusions

- Control systems with integral action gives satisfying performance with accurate following in presence of current.
- Nomoto model transformation on the VSPs evaluates good tracking properties for CSEI on heading on WP and lookahead-based LOS.
- Full state actuation is needed in maneuvering control design. The Nomoto approximation can not guarantee asymptotic stability properties.
- Maneuvering backstepping control design is depended on full state feedback. Lack of proper measurements weakens the performance significantly.
- The custom device application enables safe and robust communication between CSEI and the tablet.

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