DISCUSSION

DETERMINING ROBUST PARAMETERS IN STABILIZING SET OF BACKSTEPPING BASED NONLINEAR CONTROLLER FOR SHIP COURSE KEEPING

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(Vol 158 Part A3 2016)

COMMENT

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The authors have addressed an important topic that is needed for backstepping algorithm to guarantee the robust performance of the closed-loop system. A novel method of determining parameters was presented based on ship maneuvering empirical knowledge and closed-loop shaping theory, and theoretical proof had shown the uniformly asymptotic stability of an established nonlinear Nomoto model. However, the following important points are suggested for the improvement of this paper.

1. Parameters k_1, k_2 were defined as:

$k_1 = 0.03$, $k_2 = T / (3K) - k_1$

That is to say the signs and values of k_1, k_2 depend on K,T and the sign of k_2 was assumed to be positive. However, when K,T are of opposite signs [15], the sign of k_2 is negative, V_2 in Eq.(12) is not negative definite, and then Theorem 1 cannot be proved.

It is recommended to define the signs of δ and ψ. Normally, ψ is a variable in inertial coordinate system and δ is defined in body coordinate system. If clockwise ψ and right hand δ are set to be positive, K and T have the same sign, and a positive k_2 will ensure V, to be negative definite.

2. The values of k_1,k_2 were selected by trial and error for different ships. For example, $k_1 + k_2 \geq 100$ and $k_1,k_2 \leq 10$ are not defined rigorously. The method had achieved good control performance with. $k_1 = 0.03$, $k_2 = T / (3K) - k_1$. However, if there were perturbations caused by the changing of loading status or disturbances, k_1,k_2,K,T would have changed, and the control robustness could have not been guaranteed. It would have been better if the author tried to determine the optimal parameters in a certain method considering different ship types, loading status and complex sea conditions [16].

3. Judging by the paper, ψ_r stands for setting course, which is a constant, such as 40° in section 3. That is to say $\dot{\psi}_r$ equals zero, and formula transformation of Eq.(4) and Eq.(5) can be further simplified. However, ψ_r is a continuous differential variable in track-keeping or dynamic positioning problems, further works are recommended to focus on them.

4. The work will have better universality and engineering application significance with the following modifications. Firstly, more complicated nonlinear ship model should be used to verify the control performances; secondly, the topic should be revised to ship steering problem rather than course keeping, because the course changing performance had been indicated in simulation results; thirdly, the rationality of the rudder movements should be discussed in section 3; fourthly, two ships have been used to verify the feasibility of Theorem 1, however, comparison tests based on different loading status, ship speeds and controlling parameters are recommended to be solved in further works.

AUTHOR'S RESPONSE

Thank you again for the review's effective and serious work. The manoeuvring indexes K,T are positive toward most ships in most cases. For several special cases, the gain direction is negative when rudder angle δ is in the small interval, e.g. $\delta \in [-5°, 5°]$. However, when the rudder angel $|\delta|$ exceeds 5°, the gain direction would still be positive. Hence, the algorithm proposed in this note is practicable in the field of marine engineering.

The second suggestion is meaningful. However, that may be another idea to deal with the control problem. In this note, the proposed scheme is based on the ship model for design, i.e. the K,T are constant for the special case. Though the performance of the system response could be perturbated by the changing of loading status or disturbances, the ship model for design is the original one and the effect of the model perturbation could be still stabilizable due to the robustness of the algorithm.

The third suggestion is valuable for the control design of the ship course keeping task. Actually, for the algorithm developed in this note, the results are similar to the two cases: ψ_r is the step signal and ψ_r is the continuous differential one. And it will be illustrated by virtue of the following comparison experiment.

In this experiment, the reference course ψ_r is filtered by the second order system (1).

$$\ddot{\psi}_m + 0.1\dot{\psi}_m + 0.0025\psi_m = 0.0025\psi_r \quad (1)$$

where ψ_m is the filtered reference signal that is continuous differentiable variable, and ψ_r is the step-type reference course. In addition, the transfer function of ψ_m and ψ_r could be written as Eq.(2)

$$G(s)=\frac{\psi_m}{\psi_r}=\frac{0.0025}{s^2+0.1s+0.0025} \tag{2}$$

Comparing with the previous result, the simulation of course keeping control for Yulong and Daqing232 is showed in Figure 1 and Figure 2. It is obvious that the control effect is almost not affected by gradient course based on the analysis of Figure 1 and Figure 2.

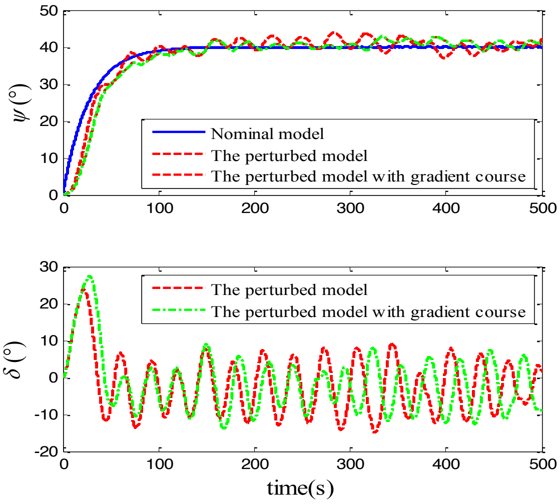

Figure 1. Simulation results of *Yulong* tanker: (a) the ship heading angle and (b) the rudder angle.

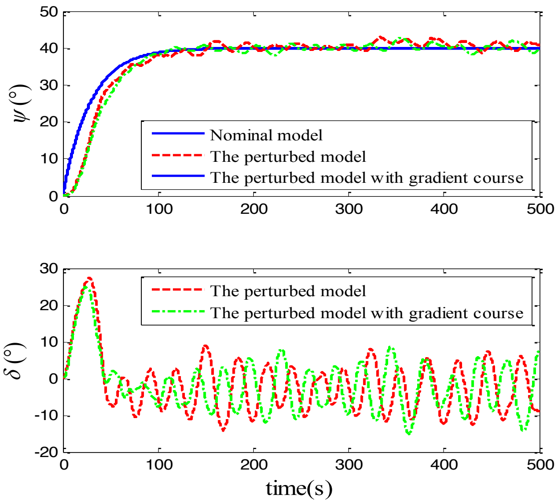

Figure 2. Simulation results of *Daqing232* tanker: (a) the ship heading angle and (b) the rudder angle.

Thank you again for **Prof. Wang**'s valuable suggestion.

On the last point, the authors appreciate Prof. Wang's valuable suggestion. However, the focused problem is the ship course keeping task in this manuscript (not the course changing steering). If possible, the author would deal with the related research topic in the further work. Thank you again.

ACKNOWLEDGEMENTS

The authors would like to thank anonymous reviewers for their valuable comments and suggestions to improve the quality of this discussion. This work is partially supported by National Natural Science Foundation of China (No. 51309002), and the Fundamental Research Funds for the Central University (Grand No. 3132016001, 3132016315).

REFERENCES

15. FOSSEN T. I. Handbook of Marine Craft Hydrodynamics and Motion Control. *Trondheim: WILEY*, 2012.
16. WANG. L, WANG. S, LIU, J, et al. Robust PID Control of Course-keeping with RRS and Its MCO based on NSGA-II. *ICIC Express Letters, v9, n11, p3113-3119*, 2015.