Applied Ocean Research 74 (2018) 142–153

Contents lists available at ScienceDirect

Applied Ocean Research

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

Genetic algorithm optimization based nonlinear ship maneuvering control

D.K. Gupta[a], K.L. Vasudev[b,*], S.K. Bhattacharyya[a,1]

[a] Department of Ocean Engineering, Indian Institute of Technology Madras, India
[b] Department of Mechanical Engineering, Hindustan Institute of Technology and Science, Rajiv Gandhi Salai, Chennai, 603103, India

ARTICLE INFO

Article history:
Received 7 April 2017
Received in revised form 20 February 2018
Accepted 1 March 2018

Keywords:
Nonlinear control
Maneuvering
Ship
Genetic algorithms
Optimization

ABSTRACT

A procedure to automatically maneuver surface ships on a given target path has been outlined in this paper. The ship maneuvering model is nonlinear. The procedure hinges on a Target Path Iteration (TPI) controller integrated with genetic algorithm (GA). GA is used to obtain the optimum command rudder angle and length of target trajectory in a particular simulation time step with the objective to minimize the mean squared error of the actual path taken by the ship vis-à-vis the target trajectory. The proposed control algorithm has been implemented on a variety of straight line and curved trajectories and the results show that the method used is accurate and robust.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Ship maneuvering is a complex problem because of ever changing environmental conditions (i.e. winds, waves and currents) and the changes in the system behaviour with changes in the draft, trim, heel, water depth, marine growth on the hull, etc. To address this control problem, the conventional techniques such as PID (Proportional, Integral and Derivative) based controllers and their variants are popular for autopilot design because of their simplicity, reliability and low cost. However, these controllers require that the user plays an active role in adjusting to and accommodating the changes in ship loading conditions and the operating environment. These classical control theories can be easily applied to linear systems or simple nonlinear systems but not to complex nonlinear systems. Ships in deep waters can be represented by linear as well as simple nonlinear maneuvering models but, as the ship comes into the shallow waters (i.e. harbour area), nonlinear effects gain prominence and a complete nonlinear model is necessary to describe the ship dynamics.

Fuzzy logic is being actively pursued for autopilot design since it has the potential to replicate experienced helmsmen, thereby producing a robust and nonlinear autopilot. In Refs. [1,2] a fuzzy autopilot for ship path control was developed where a nonlinear ship model in shallow water and a steering subsystem were used. The autopilot uses heading and yaw rate to produce a command rudder angle. In Ref. [2], an improved fuzzy autopilot using three inputs, namely, the heading error, heading rate and offset from the desired path, was proposed. An adaptive fuzzy gain autopilot composed of Sugeno type fuzzy inference in an ordinary feedback loop and an adjustable scaling factors mechanism in an additional feedback loop was developed in Ref. [3]. It also considered the influence of sea current and wave disturbances. Heading error and yaw rate were the two control inputs while the command rudder angle is the control action generated. A fuzzy autopilot that works with two error inputs (heading error and the offset from the desired path) in conjunction with a linear ship model that includes a damping term in yaw has been developed in Ref. [4].

Few attempts to use the traditional PID controllers in conjunction with modern fuzzy control has been made [5–8]. The controller constantly switches between PID and fuzzy control by considering the deviations from the desired trajectory. Heading error and rate of change of heading error are the two quantitative measures. For small deviations from the target trajectory, PID control is preferred while fuzzy control is preferred when the errors are large. Neural network based controllers have also been studied in the context of automatic maneuvering problem but they lack generalization and they tend to produce better results on the training data set than with a new set of data [9]. Some researchers [10] have turned towards Support Vector Machines (SVMs) because the generalization abilities of SVMs are better than those of neural networks [11].

* Corresponding author.
E-mail addresses: deepakforyou@gmail.com (D.K. Gupta), lakshmivasudev.k@gmail.com (K.L. Vasudev), skbh@iitm.ac.in (S.K. Bhattacharyya).
[1] Residence: C1-1-1, 2nd Cross Road, IIT Madras, Chennai 600036, India.

https://doi.org/10.1016/j.apor.2018.03.001
0141-1187/© 2018 Elsevier Ltd. All rights reserved.

Nomenclature

m	Mass of the ship
I_Z	Mass moment of inertia of the ship about the yaw-axis
u	Velocity along X-axis
v	Velocity along Y-axis
ψ	Yaw angle in the horizontal plane
$r=\dot{\psi}$	Yaw rate
δ	Rudder angle, positive when it leads to a positive yaw rate
X_G	X coordinate of ship's center of gravity (CG)
Y_G	Y coordinate of ship's center of gravity (CG)
Δu	Small perturbation to the nominal value of $u = u_0$
Δv	Small perturbation to the nominal value of $v = v_0$
Δr	Small perturbation to the nominal value of $r = r_0$
$\Delta\delta$	Small perturbation to the nominal value of $\delta = \delta_0$
u_0	Service speed
ΔX_F	Perturbation in surge force
ΔY_F	Perturbation in sway force
ΔN	Perturbation in yaw moment
U	Instantaneous forward speed of the ship (dimensional)
ρ	Sea water density
L	Length between perpendiculars (LBP)

A control strategy that has now become the industry norm for control of systems with slow dynamics is the Model Predictive Control (MPC). In MPC, the control action at any time is determined by optimization of a system-specific 'cost function' over future time. MPC is computationally intensive and often system dynamics, which may be nonlinear in nature, is assumed to be linear to cut-down the resource utilization. An implementation of MPC with a linear ship model has been recently presented in [12], where the 'cost function' is a quadratic combination of the control input and the offset of the ship from the given target path.

An attempt to guide the ship over the given trajectory using Target Path Iteration (TPI) has been made by [13]. The algorithm controlled only the command rudder angle (δ) and optimized its value, using golden section search, over a certain length of target trajectory that the ship was expected to encounter. The length of target trajectory over which δ was optimized was λ (=2) times of ship length (L). However, seeing the complexity and variety of target trajectories that can be of interest, neither this value nor any other constant value of λ can be the optimum value for all the given trajectories. In fact, the optimum value of λ for different segments of the same trajectory can also be different. Further, the optimized δ was calculated at each time step of the simulation. This would have been unnecessary in many cases. The present work addresses these issues and tries to find the optimum values for λ and δ using a nonlinear ship maneuvering model along with the TPI controller integrated with genetic algorithm (GA) approach.

Genetic algorithms are adaptive heuristic search algorithms which are based on the evolutionary ideas of natural selection and genetics [14–16]. They represent an intelligent exploitation of a random search used to solve optimization problems. Although randomized, GAs are by no means random, instead, they exploit information from previous generations to direct the search into the region of better performance within the search space. The basic techniques of the GAs are designed to simulate processes in natural systems necessary for evolution, which follow the principle of 'survival of the fittest'. GAs are capable of solving problems with multiple solutions. Since the GA is independent of the error surface, we can solve multi-dimensional, non-differential, non-continuous and even non-parametric problems. Also, in searching a large state-space, multi-modal state-space, or n-dimensional surface, GA may offer significant benefits over more typical search and optimization techniques, such as linear programming, heuristic, depth-first, breadth-first, and praxis.

2. Problem description

Real-time maneuvering of a ship over a given path requires the helmsman to look ahead for a certain distance and steer the ship accordingly. The control exerted does not usually depend upon the nature of the path beyond his field of view. A good control algorithm should play the role of an experienced helmsman.

Consider a target path ABCD as shown in Fig. 1. Let l be the length of a certain segment of ABCD which is presented to the trajectory control algorithm. The task of the algorithm is to find the command rudder angle δ which can steer the ship over l with minimal offset error. This is then a problem involving two variables, l, which is an independent variable, and δ, which depends upon l.

For example, in the path ABCD (see Fig. 1) the ship is initially at A, travelling towards D. If l is chosen as anything less than the length AB, then the algorithm sees only the straight portion of the path and should return an optimum rudder angle close to 0°. However, if l is increased, so as to include a portion of the curve BC, then the algorithm should see the port side turn and should return a corresponding optimum δ. It can be readily seen that the δ at a certain point depends on the segment length. For a straight line path AB (see Fig. 1), any choice of l < AB will lead to approximately the same value for δ (≈0°). For a zigzag path BCD, for effective path following, a single value of optimum rudder angle is impossible because the ship turns both to port and starboard. The segment length, in this case, should be chosen to be sufficiently less than the length of path BCD. It can thus be concluded that:

a) Optimum δ at any point during the path following simulation should be determined using information about the future path,
b) Optimum δ at any point depends on l chosen at that point,
c) l varies not only for different paths but also for different points on the same path, and
d) The choice of l should be such that the yaw rate does not change its sign, i.e. the ship should not turn in two different directions.

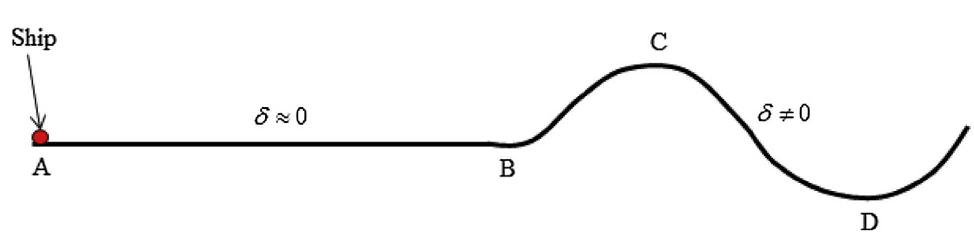

Fig 1. Definition sketch of segment length, l.

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات