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Development of cubic Bezier curve and curve-plane intersection method for parametric submarine hull form design to optimize hull resistance using CFD

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Abstract

Optimization analysis and computational fluid dynamics (CFDs) have been applied simultaneously, in which a parametric model plays an important role in finding the optimal solution. However, it is difficult to create a parametric model for a complex shape with irregular curves, such as a submarine hull form . In this study, the cubic Bezier curve and curve-plane intersection method are used to generate a solid model of a parametric submarine hull form taking three input parameters into account: nose radius, tail radius, and length-height hull ratio (L/H). Application program interface (API) scripting is also used to write code in the ANSYS design modeler. The results show that the submarine shape can be generated with some variation of the input parameters. An example is given that shows how the proposed method can be applied successfully to a hull resistance optimization case. The parametric design of the middle submarine type was chosen to be modified. First, the

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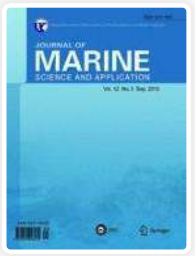

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Path-tracking control of underactuated ships under tracking error constraints

Khac Duc Do

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Path-tracking Control of Underactuated Ships Under Tracking Error Constraints

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Abstract: This paper presents a constructive design of new controllers that force underactuated ships under constant or slow time-varying sea loads to asymptotically track a parameterized reference path, that guarantees the distance from the ship to the reference path always be within a specified value. The control design is based on a global exponential disturbance observer, a transformation of the ship dynamics to an almost spherical form, an interpretation of the tracking errors in an earth-fixed frame, an introduction of dynamic variables to compensate for relaxation of the reference path generation, *p*-times differentiable step functions, and backstepping and Lyapunov's direct methods. The effectiveness of the proposed results is illustrated through simulations.
Keywords: underactuated ship; path-tracking; error constraint; Lyapunov method; backstepping method

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1 Introduction

The main difficulty with controlling an underactuated ship is that only the yaw and surge axes are directly actuated while the sway axis is not. An application of Brockett's theorem (Brockett, 1983) shows nonexistence of pure-state feedbacks that are able to asymptotically stabilize an underactuated ship at a fixed point. Thus, the stabilization problem is often solved by either discontinuous or time-varying feedback (e.g., (Reyhanoglu, 1997; Pettersen and Egeland, 1996; Aguiar and Pascoal, 2001; Mazenc *et al*., 2002; Do *et al*., 2002b)).

A global exponential position tracking system without controlling the ship's yaw angle was proposed in (Godhavn *et al*., 1998). In (Pettersen and Nijmeijer, 2001), a high-gain, local exponential tracking result was obtained based on the work in (Jiang and Nijmeijer, 1999). Based on cascade and passivity approaches, several global tracking results were obtained in (Lefeber *et al*., 2003; Jiang, 2002). Note that in (Jiang, 2002; Lefeber *et al*., 2003; Pettersen and Nijmeijer, 2001), the yaw velocity was required to be nonzero, i.e., a straight-line cannot be tracked. This restrictive assumption was removed in (Do *et al*., 2002a; 2002b; Lee and Jiang, 2004), where various relaxations on the reference trajectory and ship dynamics were made, see also (Chwa, 2011) for a solution to the tracking problem with input constraints. An assumption of low speed (nonlinear damping terms are ignored) is usually made in the above works due to the complex generation of the reference trajectories, and difficulties in stability analysis (especially stability analysis of the sway dynamics).

There are three main approaches to path-following control of ships. In the first approach, the Serret-Frenet frame is used to define the path-following (cross-track and yaw angle) errors, then the yaw moment control input is designed to stabilize these errors at the origin (e.g., (Skjetne and Fossen, 2001; Encarnação *et al*., 2000; Do and Pan, 2004; Li *et al*., 2009) for nonlinear (curved) paths, (Pettersen and Lefeber, 2001; Fredriksen and Pettersen, 2006; Moreira *et al*., 2007) for linear (straight) paths). This approach results in local results (except for the linear path) due to singularity in the cross-track error dynamics. The second approach defines the path-following objective as one of controlling the vessel so that it is in the tube of nonzero diameter centered on the path, and moves along the path with a desired speed (e.g., (Aicardi *et al*., 2001; Do *et al*., 2004; Li *et al*., 2008)). The control design aims to force the vessel to follow a virtual point moving along the path. This approach requires the vessel not be too close to the path. The third approach (referred to as path-tracking) is based on a combination of trajectory-tracking and path-following in the first approach. In the sense that the lateral path-following error is not always set to zero (to avoid singularity) and that the path parameter is used as an additional control to stabilize the lateral path-following error. Thus, global control results are often obtained (e.g., (Lapierre and Jouvencel, 2008; Do and Pan, 2006; Ghommam *et al*., 2008)).

In all of the above works on trajectory-tracking and path-following control of underactuated ships, a hard constraint on the tracking/following errors has never been addressed. This problem is important since in practice it is desired to steer the ship to be within a certain distance from the reference path, especially in narrow waterways. Moreover, various conditions on the control gains and reference paths/trajectories were imposed in the existing mentioned works to ensure boundedness of the sway velocity instead of being directly controlled in the previous control designs. The above issues motivate contributions in this paper on new controllers for asymptotic path-tracking of

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Development of Cubic Bezier Curve and Curve-Plane Intersection Method for Parametric Submarine Hull Form Design to Optimize Hull Resistance Using CFD

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Abstract: Optimization analysis and computational fluid dynamics (CFDs) have been applied simultaneously, in which a parametric model plays an important role in finding the optimal solution. However, it is difficult to create a parametric model for a complex shape with irregular curves, such as a submarine hull form. In this study, the cubic Bezier curve and curve-plane intersection method are used to generate a solid model of a parametric submarine hull form taking three input parameters into account: nose radius, tail radius, and length-height hull ratio (L/H). Application program interface (API) scripting is also used to write code in the ANSYS DesignModeler. The results show that the submarine shape can be generated with some variation of the input parameters. An example is given that shows how the proposed method can be applied successfully to a hull resistance optimization case. The parametric design of the middle submarine type was chosen to be modified. First, the original submarine model was analyzed, in advance, using CFD. Then, using the response surface graph, some candidate optimal designs with a minimum hull resistance coefficient were obtained. Further, the optimization method in goal-driven optimization (GDO) was implemented to find the submarine hull form with the minimum hull resistance coefficient (C_t). The minimum C_t was obtained. The calculated difference in C_t values between the initial submarine and the optimum submarine is around 0.26%, with the C_t of the initial submarine and the optimum submarine being 0.001 508 26 and 0.001 504 29, respectively. The results show that the optimum submarine hull form shows a higher nose radius (r_n) and higher L/H than those of the initial submarine shape, while the radius of the tail (r_t) is smaller than that of the initial shape.

Keywords: submarine hull form; parametric design; cubic Bezier curve; curve-plane intersection method; hull resistance coefficeint; parametric design; goal-driven optimization (GDO); computational fluid dynamic (CFD); ANSYS

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1 Introduction

Recently, the relationship between parametric design and ship performance analysis using CFD has become a topic of interest, specifically, the method of obtaining an optimum ship hull form that will ensure good hydrodynamic performance of a ship. Several methods of parametric design have been used in ship modeling. The use of the control points of the cubic B-spline to generate the parameters of ship hull design has been introduced with successful results (Sarioz, 2006; Mancuso, 2006; Perez *et al*., 2007; Ping *et al*., 2008, Perez and Clemente, 2011). Campana *et al*. (2006) used the Bezier polynomial patches method, in which the shape modification was controlled by a given number of control points that were used as the design variables/input parameters for finding the optimum shape in the optimization process. Chen and Huang (2004) used a technique for parameter estimation using the B-spline surface fitting method in an inverse design problem of finding the optimal hull form. In addition, Kang and Lee (2010) implemented the parametric morphing technique to rapidly generate a hull form with some variations of the input parameters. Furthermore, Rodriguez and Jambrina (2012) developed a programmed design based on a programming language as a tool for parametric hull form generation. In general, these methods can be used to create the parametric design for surface modeling only. However, some CFD software (especially the RANSE solver) needs a solid modeling at the meshing stage before the CFD analysis stage can begin. Pecot *et al*. (2012) introduced the parametric design of ship hull shape for solid modeling in the optimization calculation using CFD. In this design, CAD is used to generate some bulbous bow shapes based on the parameters for each design of experiment (DOE). Blanchard *et al*. (2013) used the movement of control points to create bulbous bow shapes in solid modeling according to two parameters: bow length and bow thickness. However, neither of these authors considered how to automatically generate the hull or bulbous bow shape.

In this study, some previous studies concerning ship performance analysis using CFD, especially for the free surface case, are used as a reference for the calculation of ship resistance. Seo *et al*. (2010) investigated flexible meshing techniques (i.e., a hybrid meshing for complex

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Corrosion Resistance of AA6063-Type Al-Mg-Si Alloy by Silicon Carbide in Sodium Chloride Solution for Marine Application

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Abstract: The present work focused on corrosion inhibition of AA6063 type Al-Mg-Si alloy in sodium chloride (NaCl) solution with a silicon carbide inhibitor, using the potentiodynamic electrochemical method. The aluminium alloy surface morphology was examined, in the as-received and as-corroded in the un-inhibited state, with scanning electron microscopy equipped with energy dispersive spectroscopy (SEM-EDS). The results obtained via linear polarization indicated a high corrosion potential for the unprotected as-received alloy. Equally, inhibition efficiency as high as 98.82% at 10.0 g/v silicon carbide addition was obtained with increased polarization resistance (R_p), while the current density reduced significantly for inhibited samples compared to the un-inhibited aluminium alloy. The adsorption mechanism of the inhibitor aluminium alloy follows the Langmuir adsorption isotherm. This shows that the corrosion rate of aluminium alloy with silicon carbide in NaCl environment decreased significantly with addition of the inhibitor.

Keywords: corrosion resistance; silicon carbide; sodium chloride (NaCl); aluminium alloy; interface; inhibition efficiency; thin film; adsorption isotherm; potentiodynamic electrochemical method; marine application

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1 Introduction

Corrosion is believed to be one of the major problems affecting the durability, performance, safety, and appearance of materials in most service conditions. In these conditions and in various industries, such as chemical and construction, safely and cost reduction are of great priority. Corrosion affects all areas of the economy and it has been estimated that the cost of corrosion in an industrialized nations is more than 4% of Gross National Product, as reported by Suleiman *et al.* (2013), Mohammed *et al.* (2013) and Singh *et al.* (2012). Here for example, the physical properties of this aluminium alloy can be obtained easily, but the effects of corrosion deter its selection. Also, an increase in corrosion resistance comes with an increase in cost. Aluminium alloys have considerable corrosion resistance in most environments; however, their resistance to corrosion in some aggressive environments like chloride is still a research concern. In the efforts toward identifying corrosion control method(s), the use of inhibitors often offers an alternative low cost way of combating corrosion, as stated by Fouda *et al.* (2009), Oguzie *et al.* (2004), Rahim and Kassim (2008), Rahim *et al.* (2007) and Amin and Khaled (2010). However, most inhibitors are considered to be toxic, expensive, and not eco-friendly. With increasing environmental awareness and the disadvantages of some chemicals, recent research is now tailored towards exploring some organic and non-toxic inhibitors. This leads to developing cheap and environmentally acceptable corrosion inhibitors, according to Obot *et al.* (2011) and Ogoko *et al.* (2009). In our previous studies: Abdulwahab *et al.* (2013), Fayomi *et al.* (2013) and Popoola *et al*. (2012a), various eco-friendly inhibitors have been used successfully for aluminium based alloy in different experimental conditions producing a high level of inhibition. This clearly showed that continued effort toward identifying new but promising corrosion inhibitors is important. This study, used polarization techniques to evaluate silicon carbide as a corrosion inhibitor for an aluminium alloy in sodium chloride solution.

2 Experimental procedures

2.1 Materials and methods

Aluminium alloy type AA6063, sized 20 mm×20 mm×3 mm with the chemical composition shown in Table 1, was sourced from the Surface Engineering Research Centre (SERC) of Tshwane University of Technology, Pretoria. The aluminium alloy was in the form of corrosion coupons to be immersed in 3.5% NaCl static solution with and without silicon carbide (SiC) inhibitor. In preparation, the coupons were abraded mechanically with 220, 400, 600, 800 and 1 000 grid emery paper, degreased with acetone and rinsed with distilled water. The initial weight of each sample coupon was then recorded. The silicon carbide was obtained in powdered form from the Technology Innovation Agency,

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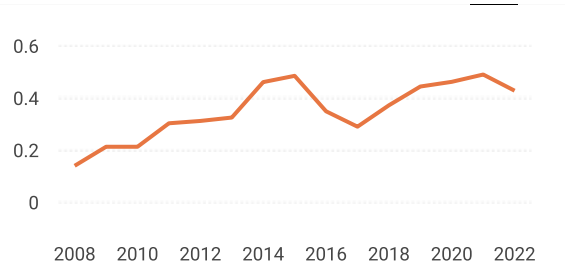

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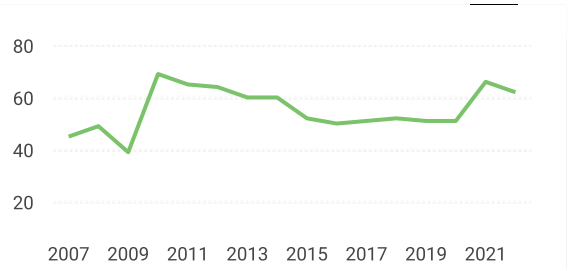

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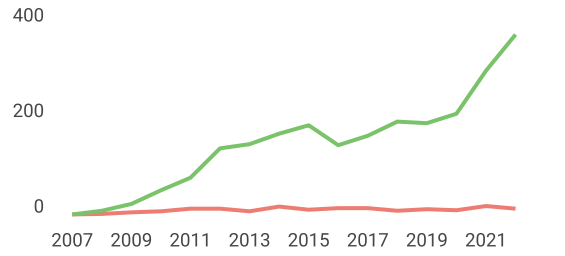

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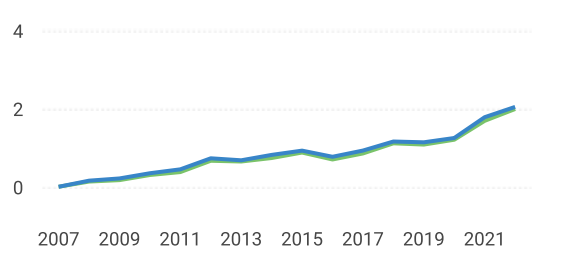

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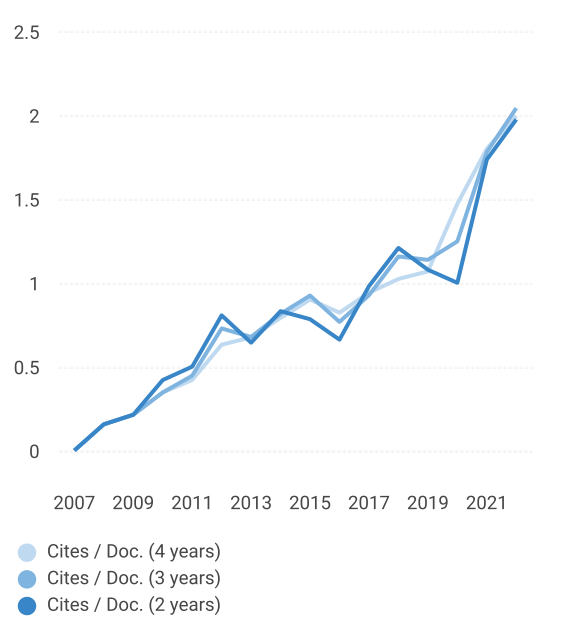

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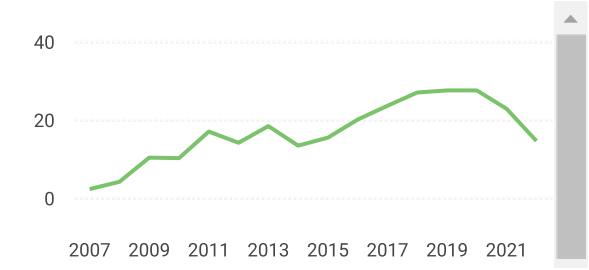

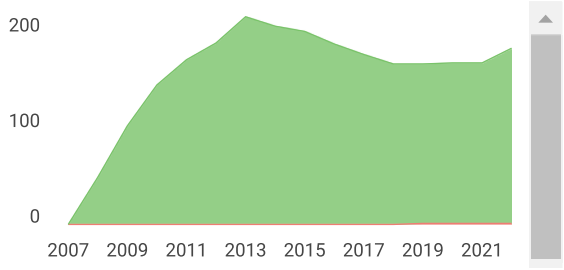

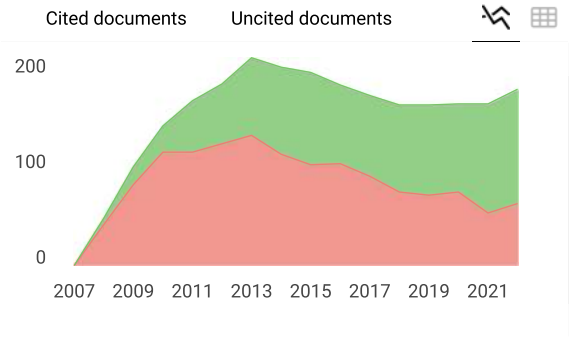

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