EVOLUTIONARY ALGORITHMS FOR SHIP HULL SKINNING APPROXIMATION

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EVOLUTIONARY ALGORITHMS FOR SHIP HULL SKINNING APPROXIMATION

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To my beloved mother and father

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ABSTRACT

Traditionally, the design process of a hull involves simulation using clay models. This must be done cautiously, accurately and efficiently in order to sustain the performance of ship. Presently, the current technology of Computer Aided Design, Manufacturing, Engineering and Computational Fluid Dynamic has enabled a 3D design and simulation of a hull be done at a lower cost and within a shorter period of time. Besides that, automated design tools allow the transformation of offset data in designing the hull be done automatically. One of the most common methods in constructing a hull from the offset data is the skinning method. Generally, the skinning method comprised of skinning interpolation and skinning approximation. Skinning interpolation constructs the surface perfectly but improper selection of parameterization methods may cause bumps, wiggles, or uneven surfaces on the generated surface. On the other hand, using the skinning surface approximation would mean that the surface can only be constructed closer to data points. Thus, the error between the generated surface and the data points must be minimized to increase the accuracy. Therefore, this study aims to solve the error minimization problem in order to produce a smoother and fairer surface by proposing Non Uniform Rational B-Spline surface using various evolutionary optimization algorithms, namely, Gravitational Search Algorithm, Particle Swarm Optimization and Genetic Algorithm. The proposed methods involve four procedures: extraction of offset data from line drawing plan; generation of control points; optimization of a surface; and validations of hull surfaces. Validation is done by analyzing the surface curvature and errors between the generated surface and the given data points. The experiments were implemented on both ship hull and free form models. The findings from the experiments are compared with interpolated skinning surface and conventional skinning surface approximation. The results show that the optimized skinning surfaces using the proposed methods yield a smaller error, less control points generation and feasible surfaces while maintaining the shape of the hull.

ABSTRAK

Secara tradisional, proses merekabentuk lambung kapal melibatkan simulasi menggunakan model tanah liat. Ini perlu dilakukan dengan berhati-hati, teliti dan berkesan bagi mengekalkan prestasi kapal. Pada masa sekarang, teknologi terkini Rekabentuk Berbantukan Komputer, Pembuatan, Kejuruteraan dan Penghitungan Dinamik Cecair telah membolehkan rekabentuk 3D dan simulasi merangka kapal dijelmakan secara berkesan dengan kos yang minima dalam masa yang singkat. Disamping itu, alat reka bentuk otomatik membolehkan transformasi data *offset* yang digunakan dalam merekabentuk lambung kapal dilakukan secara otomatik. Salah satu daripada kaedah yang umum digunakan adalah kaedah pengulitan permukaan. Secara amnya, kaedah pengulitan permukaan ini terdiri daripada pengulitan permukaan interpolasi dan pengulitan permukaan penghampiran. Kaedah pengulitan permukaan interpolasi membina permukaan dengan sempurna, namun pemilihan parameter yang tidak sesuai boleh menyebabkan lekukan, herotan dan permukaan yang tidak sekata. Selain itu, penggunaan kaedah pengulitan penghampiran bererti bahawa permukaan hanya boleh dibina daripada titik data yang berhampiran. Oleh yang demikian, ralat di antara permukaan terjana dan titik data masukan harus dikurangkan bagi meningkatkan ketepatan. Justeru itu, kajian ini bertujuan untuk menyelesaikan masalah pencarian ralat terkecil bagi menghasilkan permukaan yang halus dan tepat dengan mencadangkan kaedah *Splin-B* Nisbah Tak Seragam terhadap permukaan dengan melaksanakan pelbagai algoritma pengoptimuman evolusi, termasuk, Algoritma Carian Bergraviti, Pengoptimuman Partikel Berkelompok dan Algoritma Genetik. Kaedah cadangan ini mengandungi empat prosedur: penyarian data *offset* daripada lakaran pelan garis; penjanaan titik kawalan; pengoptimuman permukaan; dan pengesahan permukaan lambung. Pengesahan dilakukan dengan menganalisa lengkungan permukaan dan ralat antara permukaan terjana dan titik data yang diberikan. Ujikaji telah dilaksanakan terhadap kedua-dua lambung kapal dan model berbentuk bebas. Hasil kajian dibandingkan dengan pengulitan permukaan yang telah diinterpolasi dan penghampiran pengulitan permukaan konvensional. Keputusan yang diperolehi mendapati bahawa pengulitan permukaan yang sangat optima menggunakan kaedah cadangan tersebut menghasilkan ralat yang kecil, penjanaan titik kawalan yang sedikit dan permukaan tersaur serta mengekalkan rupabentuk lambung kapal tersebut.

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LIST OF ABBREVIATIONS

ABBREVATION	DESCRIPTION
2D	(x, y)-Two dimensional plane
3D	(x, y, z)-Three dimensional plane
4D	(x, y, z, w)-Four dimensional plane
BTV	Buoy Tank Vessel
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAGD	Computer Aided Geometric Design
CFD	Computational Fluid Dynamics
CASD	Computer Aided Ship Design
FFH	Fire Fighting Hull
FVH	Fishing Vessel Hull
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
PSO	Particle Swarm Optimization
IGES	Initial Graphics Exchange Specification
LOD	Length of Details
NFL	No Free Lunch
NURBS	Non-Uniform Rational B-Spline

LIST OF SYMBOLS

SYMBOLS		DESCRIPTION
δ	-	Error between the curve and the given data points.
$B_{i,n}(t)$	-	Bezier basis function of ith control points with $n+1$ control points.
$C(t)$	-	Curve with parameter t.
$C_k(t)$	-	k^{th} cross sectional curve with parameter t.
D_{ij}	-	i^{th} cross sectional curve of jth data point.
d	-	Degree of the curve on u direction.
e	-	Degree of the curve on v direction.
$E_{surface}$	-	Error between the surface and the given data points.
$\kappa(x)$	-	Curvature value on arbitrary point x.
m	-	Number of data points on u direction (surface).
m_i	-	Number of data points of ith cross sectional curve on u direction (surface).
n	-	Number of data points on v direction (surface).
n_i	-	Number of data points of ith cross sectional curve on v direction (surface).

$N_{i,d}(t)$	-	B-Spline basis function of ith control points with degree d.
P_i^w	-	i^{th} control points as homogenous coordinate.
P_i	-	i^{th} control points.
r_{error}	-	Reduced error.
$R_{i,d}(t)$	-	NURBS basis function of ith control points with degree d.
$S_k(u,v)$	-	Skinning surface value at parameter u and v.
$S(u,v)$	-	Surface value at parameter u and v.
t_i	-	i^{th} parameter.
T	-	A set of parameter values.
u_i	-	i^{th} knot value on u direction.
v_i	-	i^{th} knot value on v direction.
U	-	Knot vector on u direction.
V	-	Knot vector on v direction.
w_i	-	i^{th} control point weight.
c_1	-	PSO constant number.
c_2	-	PSO constant number.
$a_i^d(t)$	-	The acceleration of ith agent of dimensional d at t^{th} iteration.
$F_i^d(t)$	-	The total force of ith agent at t^{th} iteration.
$G(t)$	-	The gravitational constant at t^{th} iteration.
$m_i(t)$	-	The inertia mass of ith agent at t^{th} iteration.
$M_i(t)$	-	The mass of ith agent at t^{th} iteration.
$x_i^d(t)$	-	The position of ith particle/agent/ individual of d dimension at t^{th} iteration.
$v_i^d(t)$	-	The velocity of ith particle/agent of d dimension at t^{th} iteration.
$p_i^d(t)$	-	The *pbest* of ith particle.

$g^d(t)$	-	The *global best* of particles.
$w(t)$	-	PSO moment inertia.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Over the centuries, ships that are used by humans began with the discovery of boat, canoe, and raft. Ship is a vehicle larger than boat that carries passengers or cargo to sail or navigate across the water (Farley, 2010). In the U.S. Navy, the term boat refers to any water vehicles that can be carried by a ship as a rule thumb saying goes: “a boat can fit on a ship, but a ship cannot fit on a boat” (WordIQ, 2010). Thus, all submarines and mid ship-size, e.g. steamboats, are often referred as boats; whereas, seagoing water vehicles are large enough to be called ships which were used in ancient times by Greeks, Romans, Chinese, and Egyptians. At the beginning, all the ancient ship were propelled by wind, sails or oars and made from wood, bamboo or papyrus rods as a shipbuilding material. However, since the discovery of the steam engine and the use of iron and steel, modern ships have been equipped with steam engines, diesel and even nuclear, as the propulsion and steel as raw shipbuilding material (Mason, 1977; Blackburn, 1982; Rawson and Tupper, 2001). There many types of ships; not only on steam ship, but also the floating boat on the water like a hovercraft and water vehicles used in the bottom of the sea called

submarine. Basically, ship classification will be based on hull shape, propulsion equipment, based material, type of lift, and its usage (Figure 1.1).

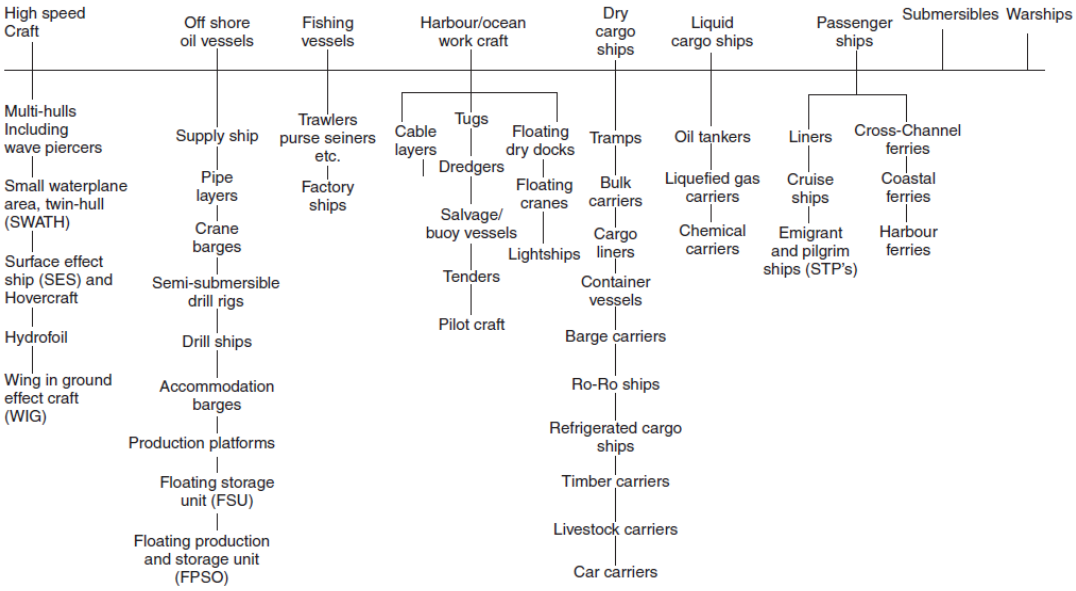

Figure 1.1 Ship Categories (Eyres, 2007)

The ship itself can be divided into several basic parts: bow, bulbous bow, hull, deck, superstructure, smokestack, stern, rudder, and propeller (Figure 1.2). Among the others, hull is the most important main body of a ship that needs more attention during ship design due to its role in determining the shape and the performance of the entire ship. The hull ranges from mono-hull to multiple hulls as catamaran type.

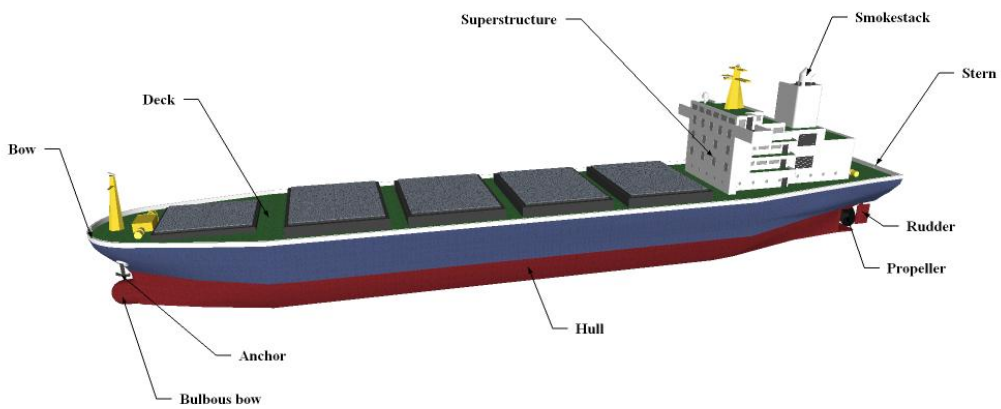

Figure 1.2 Main Parts of Ship

In the history of naval hull design, from wood to steel period, engineers have always been inspiring to improve the structure and shape of the hull. This is due to the importance of hull design in reducing the damage when collision occurs, improving ship speed, and strong enough against rust caused by corrosion as hull kept floating on the water except the hovercraft ship type. As the hull shape of the ship affects the speed and capacity of the ship, its performance depends on varieties of hull shapes. Therefore, the best hull shape is depending on the usage of the ship; for example, Cargo ship has a big shape since it is used for long distance and operates for all seasons with its big capacity (Sorum, 2007). As the hull is crucial to engineer, thus, it will take more time and cost to design an optimal hull form, speed, and capacity. Therefore, scientist has been searching alternative solutions to reduce the time and costs without sacrificing the quality. Conventionally, ship models are represented by the clay model. Figure 1.3 shows the clay model of Monitor M33 ship. Few years later, the clay model is changed to drawing board (Sapidis, 1994) and later transformed to 3-D hull using Computer-aided Design (CAD) and Computational Fluid Dynamics (CFD).

Figure 1.3 Monitor M33 Ship Clay Model (Pinniger, 2007)

With the aid of CAD and CFD, time and cost can be minimized in designing ship hull surface. Curves and surfaces are the central of the geometric modeling which is the essence of the CAD/CAM. Many studies have been done for almost 50 years to find a new type of surface to conform to certain requirements, and these include (Farin, 1989):

1. Fit a set points.
2. Predictable changes.
3. Flexibility surface.
4. Continuity, both tangency continuity, and curvature continuity.

The emergence of Bezier, B-Spline, and NURBS curves as standard mathematical modeling method for geometrical design and geometrical data exchange has enriched the hull design respectively. However, in certain applications, improvements need to be done to obtain better curves or surfaces in terms of accuracy, rendering time, smoothness, fairness shape surfaces, and pleasing to the eyes (Bona *et al.*, 1973).

1.2 Background of Study

In geometric modeling, mathematical techniques on curves and surfaces are required to represent an existing both 2D and 3D object. There are three most common methods for representing a curve and surface in geometric modeling: implicit, explicit, and parametric representation. Parametric representation is the most useful compared to the others since the explicit representation cannot represent a vertical line and the implicit representation can be used only when the function is known.

Practically, in the geometric modeling, a curve and surface can be constructed not only from cloud of points, but also from some of profile curve, known as cross-sectional curve. This type of surfaces can be divided into six surfaces: surface of revolution, extruded, ruled, swung, swept, and skinning surface. Among them, skinning surface is the most common approach used to represent complex surfaces

and has been applied in many areas such as marine automotive, medical, and aircraft industry. The skinning method is first introduced by Ball (1974, 1975, 1977). He proposed new curve that based on cubic curve known as Ball curve and implemented for lofting procedure on CONSURF software. Woodward (1988) developed skinning methid based on B-Spline curve interpolation. However, this approach has a drawback which may lead to the explosion of control points during skinning process. Eight years later, Piegl and Tiller (1996) developed a technique for reducing control points that used for skinning method. In addition, Piegl and Tiller (2002) proposed a revisited skinning method that eliminates all anomalies by replacing the cross sectional curves with well parameterized non-rational approximants. Nasri *et al.* (2003) developed a skinning method using Catmull-Clark curve which can be defined on incompatible control polygons. While Park *et al.* (2004) proposed skinning method based on universal parameterization and use the highest number of control points as number of control points for each compatible B-Spline. Few years later, Shamsuddin *et al.* (2006) developed new parameterization method, hybrid parameterization method, and used to establish new skinning method. Despite this method can be reduced more control points compared to Piegl's and Park's method, the method is still unstable due to the weaknesses of hybrid parameterization method. Currently, Wang *et al.* (2008; 2009) proposed new method on interpolation skinning method. The proposed method is equipped by the examination of the existence of the solution of each cross sectional curve. The resulting surface shows that the proposed method can reduce more control points of the surface for some cases.

In marine industry, especially in ship hull design, skinning method has been developed to construct the ship hull surface. Before skinning method is used, scientist uses bi-cubic coons patch surface to represent a ship hull surface. Since the discovery of Bezier and B-Spline curve and surface, engineers started to develop B-Spline surface as hull representation (Rogers, 1977; Rogers and Steven, 1980; Rogers *et al.*, 1983; Standerski, 1989). Since the NURBS curve is known to have advantages compared to its predecessor, scientists began to develop NURBS skinning surface for hull shape representation (Nam and Parsons, 2000; Wen *et al.*, 2005; Shamsuddin *et al.*, 2006; Lu *et al.*, 2007, 2008). Although NURBS skinning surface of the hull surface is well represented, but improvements are still needed to

enhance some unwanted and unfair surfaces due to interpolation and selection of parameterization methods (Figure 1.4). Moreover, the rational form of NURBS curve will lead the equation system into system of nonlinear equations.

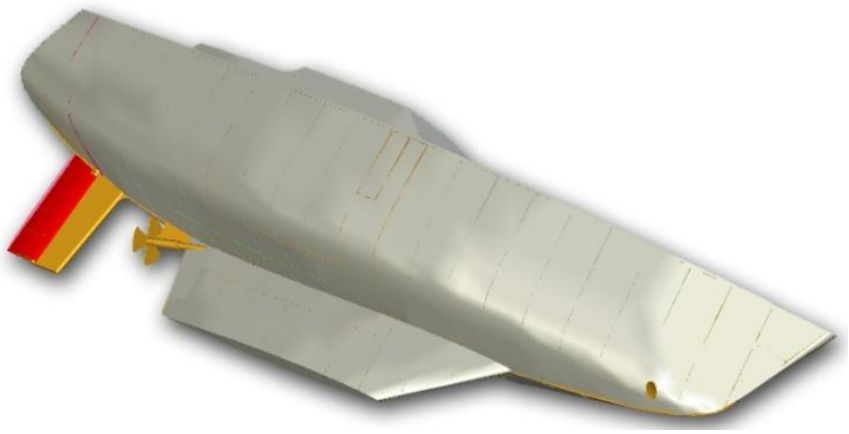

Figure 1.4 The Resulting Surface of Skinning Interpolation Method (Mason, 2004)

According to Rogers (2001), the unfair and unsmooth surface can be removed by reducing the number of control points. In the ship hull shape generation, many works have been done in constructing a fair hull surface (Farin *et al.*, 2002; Munchmeyer, 1979; Rhinoceros®, 2001; Formation, 2006; Wen *et al.*, 2005, 2006; Sarioz, 2006; Pérez *et al.*, 2008). Farin *et al.* (2002) had constructed the fairing process manually. Munchmeyer (1979) developed a fair hull surface using B-Spline, Rhinoceros® (2001), 3D modeler software, offering fairing ship hull surface manually. Since the development of the computational intelligence techniques, the manual fitting and fairing process can be done automatically. In addition, the integration of the evolutionary technique is to overcome the problem such as non linear form, the unstructured input data, the arbitrary order of the surface, and the unknown of the objective function. The famous 3D ship hull modeler software, Maxsurf, generates fairness surface automatically using Genetic Algorithm approach (Formation, 2006). Wen *et al.* (2005; 2006) developed a fair ship hull surface using NURBS interpolation skinning method and optimized by using simulated annealing for fairing and surface fitting. Sariöz (2006) developed ship hull fairing process based on variation optimization approach and curvature color analysis for fairing

assessment. Pérez *et al.* (2008) developed an iterative algorithm to obtain optimized parameterization for cubic spline curve that approximate the hull offset data points. Later, Kim (2009) proposed a multi-objective Particle Swarm Optimization (PSO) in ship design to solve non linear Partial Differential Equation (PDE) with the aid of artificial neural network. In general, the fitting and fairing process are done by using evolutionary algorithm such as Genetic algorithm, simulated evolution, and simulated annealing. In other word, the optimization process is conducted automatically. The result of the evolutionary algorithm is promising in generating the ship hull surface though there are some weaknesses such as the computation time and unwanted surface may be generated.

The above issues address the advantages and weaknesses of the current ship hull design. Among of the weaknesses are the unfairness of the surface and numerous number of control points may be generated. Therefore, in this study, skinning method will be developed to generate fair and smooth surfaces for complex objects.

1.3 Problem Statement

As shown in Figure 1.4, the skinning interpolation method has a drawback when rendering the hull of the surface due to the interpolation and selection of parameterization method. This may occur when the cross sectional curve of the ship hull surface that may have unevenly spaced isoparm, which is connection lines between u and v direction coordinate values. As a result, the ship hull surface may have an unfair surfaces. As mentioned in previous section, the unfairness surface could be reduced by decreasing the number of control points which can be performed by conducting approximation method. Despite that, the approximation method has

disadvantage which could modify the shape of the curves and surfaces. Hence, the main research question for this study can be stated as:

"How to obtain a fair and smooth ship hull surface using skinning approximation method"?

1.4 Research Aim

The aim of the study is to obtain smooth hull surfaces with minimal control points using single NURBS surface.

1.5 Research Objectives

To achieve the goal of the study, few objectives are provided as below:

1. To develop optimized NURBS skinning method based on surface approximation.
2. To optimize the proposed method using genetic algorithm (GA), Particle Swarm Optimization (PSO), and Gravitational Search Algorithm (GSA) to obtain smooth surface with small number of control points.
3. To visualize, validate, and compare the result with the conventional skinning interpolation, proposed skinning approximation, optimized skinning approximation method.

1.6 Research Scopes

The scope of the study is based on:

1. Real ship hull data known as offset drawing data will be used. The set of data are consisting of:

    a. Body plan,
    b. Half breadth plan, and
    c. Sheer plan drawing.

2. The optimization of the surfaces to obtain the weights of the surface is conducted by using search algorithms: GA, PSO, and GSA.
3. The analysis of the proposed methodology will be validated using error and Gaussian curvature of the surface.
4. The comparison will be done with the conventional method.
5. Speed/running time of the algorithm is not the concern of this study, since in the engineering field accuracy is more valuable than the running time of an algorithm.
6. The visualization of the proposed method will be performed using openGL and C++ programming language.

1.7 Thesis Organization

This thesis is organized into six chapters as follows: First chapter provides the reader with an overview of the research which includes the definition and history of the ship, the importance of hull, and current method for constructing ship hull surface. The common methods for constructing ship hull shape, skinning method,

and some corresponding studies are also introduced. In addition, the first chapter will discuss the problem statement, the aim, the objective, and the scope of this research. Finally, the organization of the study is presented.

Second chapter will be focused on basic mathematics about curve, surfaces, parameterization, knot generation; curve, and surface fitting, both interpolation and approximation, optimization method that related to this research and some general methods of surface reconstruction will be discussed. The main part of this chapter will discuss about some background of computer aided in ship hull design and surface skinning method.

Third chapter presents the proposed framework design of this study. In addition the implementation of the conventional method is given in this chapter. However, the implementation of the Proposed and Optimized proposed skinning surface approximation method are separated into different chapters. Furthermore the implementation on NURBS surface and Gaussian surface curvature are provided in this chapter.

Fourth chapter provides in detail the proposed skinning surface approximation methods and implementations. This chapter is divided into two sections: the proposed and optimization of the proposed skinning method. The optimizations of the proposed skinning method using GA, PSO, and GSA are described. Furthermore, the details of each algorithm are also given in this chapter.

Fifth chapter provides the result and discussion of this research. The experiment is conducted for various free surface and ship hull model. The analysis of the result is also provided in this chapter. The analysis includes the accuracy of the surface, which represented by error of surface, and Gaussian curvature analysis.

Sixth chapter presents in brief conclusion of this study. The limitation of this study is also described in this chapter. Furthermore, the future works of this study of what can be used for further research is suggested at the end of this chapter.

REFERENCES

Abu Qudeiri, J., Yamamoto, H., Ramli, R. (2007). Optimization of Operation Sequence in CNC Machine Tools Using Genetic Algorithm. *Journal of Advanced Mechanical Design, Systems, and Manufacturing*, 1(2), 272-282, J-STAGE.

Ahmed Mohamed, M. A. (2005). *Development of hybrid skinning surface method for ship hull design*. PhD thesis. UniversitiTeknologi Malaysia, Skudai.

Adi, D.I.S., Shamsuddin, S. M., Ali, A. (2009). Particle Swarm Optimization for NURBS Curve Fitting. *Proceeding. of the Sixth international Conference on Computer Graphics, Imaging and Visualization CGIV 2009*, Washington, DC, IEEE, 259-263.

Adi, D.I.S., Shamsuddin, S. M., Hashim, S. Z. (2010). NURBS Curve Approximation Using Particle Swarm Optimization. *Proceeding. of the seventh international Conference on Computer Graphics, Imaging and Visualization CGIV 2010*, Australia, IEEE, 73-79.

Ball, A. A. (1974). CONSURF. Part one: introduction of the conic lofting tile. *Computer-Aided Design*, 6(4), 243-249. Elsevier.

Ball, A. A. (1975). CONSURF. Part two: description of the algorithms. *Computer-Aided Design*, 7(4), 237-242. Elsevier.

Ball, A. A. (1977). CONSURF. Part 3: how the program is used. *Computer-Aided Design*, 9(1), 9-12. Elsevier.

Balic, J. (2006). Intellegent CAD/CAM Systems for CNC Programming - an Overview. *Advances in Production Engineering And Management*, 1(1), 13-22. APEM.

Baskar, N., Asokan, P., Prabhaharan, G., Saravanan, R. (2005). Optimization of Machining Parameters for Milling Operations Using Non-conventional

Methods. *The International Journal of Advanced Manufacturing Technology*, 25(11), 1078-1088, Springer-Verlag.

Blackburn, G. (1982). *The Illustrated Encyclopedia of Ships, Boats, and Vessels*. New York, OverlookPr Woodstock.

Blancke, S., Boudry, M., Braeckman, J. (2010). Simulation of biological evolution under attack, but not really: a response to Meester. *Biology and Philosophy*, 1-6. Springer Netherlands.

Bole, M. and Lee, B. S. (2006). Integrating Parametric Hull Generation into Early Stage Design. *Ship Technology Research*, 53(3), 115-137, Institute of Ship Technology and Ocean Engineering.

Bona, C., Galletti, A., Lucifredi (1973). Computer-aided automatic design, *Mechanism and Machine Theory*, 8(4), 437-456. Elsevier.

Boor, C. D. (2001). *A Practical Guide to Splines (revised edition)*. New York. Springer.

Campana, E., Liuzzi, G., Lucidi, S., Peri, D., Piccialli, V., Pinto, A. (2009). New global optimization methods for ship design problems. *Optimization and Engineering*. 10(4), 533- 555. Springer-Verlag.

Chapman and Hendry, F. (1760). *A treatise on ship-building*. London, Cambridge.

Chiong, R. (2009). *Nature-Inspired Algorithms for Optimisation 1st edition*. Springer Publishing Company, Incorporated.

Cobo, A., Gálvez, A., Puig-Pey, J, Iglesias, A., Espinola, J. (2008). Bio-Inspired Metaheuristic Methods for Fitting Points in CAGD. *International Journal of Computer Information Systems and Industrial Management Applications*. 1(1), 36-47.

Coons, A. (1967). Surfaces for Computer-Aided Design of Space Forms, *Technical Report MAC-TR-41*, MIT, Cambridge, MA

Dejhalla, R., Mrsa, Z., Vukovi, S., Cacute (2001). Application of Genetic Algorithm for Ship Hull Form Optimization. *International Shipbuilding Progress*, 48(2), 117-133. IOS Press.

Dembski, W.A. (2002). *No free lunch: why specified complexity cannot be purchased without intelligence*. Lanham MD, Rowman & Littlefield Publishers.

Dimas, E. and Briassoulis, D. (1999). 3D geometric modelling based on NURBS: a review. *Advances in Engineering Software*, 30(9-11), 741-751, Elsevier.

Eberhart and Shi, Y. (2001). Particle swarm optimization: developments, applications and resources, *Proceedings of Congress on the Evolutionary Computation 2001*, Seoul, South Korea. IEEE, 81-86.

Elkeran, A. and El-Baz, M.A. (2003). NURBS Feedrate Adaptation for 3-Axis CNC Machining, *Maintenance Resources e-zine*, August 2003, 17-37.

Eyres, D. J. (2007). *Ship Construction 5th edition*. London, Butterworth-Heinemann.

Farin, G. (1989). Trends in Curve and Surface Design. *Computer-Aided Design*, 21(5), 293-296. Elsevier.

Farin, G. (1992). From Conics to NURBS: A Tutorial and Survey. *Computer Graphics and Applications*. 12(5), 78-86. IEEE.

Farin, G., Hoschek, G., Kim, M. S. (2002). *Handbook of Computer Aided Geometric Design*. North Holland, Elsevier.

Farin, G. E. (2002). *Curves and surfaces for CAGD a practical guide*. San Francisco, CA, Morgan Kaufmann.

Farley. (2010). Ship. *The Free Dictionary*. Retrieved Accessed July 12, 2010, from http://www.thefreedictionary.com/ship.

Foley, J. D., Dam, A. v., Feiner, S., Hughes, J. (1995). *C Edition, Interactive Computer Graphics: Principles and Practice*. Reading, MA, Addison-Wesley.

Foley, T. A. (1987). Interpolation with interval and point tension controls using cubic weighted v-splines. *ACM Transactions on Mathematical Software*, 13(1), 68-96. ACM.

Formation, D. S. (2006). *Maxsurf User Manual.* Formation Design Systems Pty Ltd.

Galvez, A., Iglesias, A., Cobo, A., Puig-Pey, J., Espinola, J. (2007). Bezier curve and surface fitting of 3D point clouds through genetic algorithms, functional networks and least-squares approximation. *Lectures Notes in Computer Science*. 4706/2007. 680-693. Springer-Verlag.

Galvez, A., Cobo, A., Puig-Pey, J., Iglesias, A. (2008). Particle Swarm Optimization for Bézier Surface Reconstruction, Computational Science, *Lecture Notes in Computer Science*, 5102, 116 – 125. Springer Berlin.

Galvez, A. and Iglesias, A. (2010). Particle Swarm Optimization for non-uniform rational B-spline surface reconstruction from clouds of 3D data points, *Information Sciences*, In Press, Corrected Proof, doi: 10.1016/j.ins.2010.11.007. Elsevier.

Gammon, M. A. (2004). *Ship Hull Form Optimization by Evolutionary Algorithm*. PhD Thesis. Yildiz Technical University, Istanbul.

Gordon, W.J. and Riesenfeld, R.F. (1974). *B-spline Curves and Surfaces in Computer Aided Geometric Design*. New York: Academic Press.

Hansel, B. (2008). Notus Racing and Cruising Canoe: An exercise in using FREE!ship, *Lightweight canoe and kayak travel*, Retrieved September 23, 2010, from http://www.paddlinglight.com/articles/notus-racing-and-cruising-canoe-an-exercise-in-using-freeship/

Hoschek, J. and Lasser, D. (1993). *Fundamentals of Computer-Aided Geometric Design.* Wellesley, Mass: A.K. Peters.

Huang, Q., Hu, S., Martin, R. R. (2005). Fast degree elevation and knot insertion for B-spline curves. *Computer Aided Geometric Design*, 22(2), 183-197. Elsevier.

Islam, M. M., Khondoker, M. R. H., Rahman, C. M. (2001). Application of artificial intelligence techniques in automatic hull form generation, *Ocean Engineering*, 28(12), 1531-1544. Elsevier.

Jing, Z., Shaowei, F., Hanguo, C. (2009). Optimized NURBS Curve and Surface Modelling Using Simulated Evolution Algorithm. *Proceeding of Second International Workshop on Computer Science and Engineering 2009*, Qingdao, China, IEEE, 435-439.

Jones, T. M. (2005). *AI Application Programming (Charles River Media Programming)*. Rockland, MA, USA, Charles River Media, Inc.

Jung, H.B., Kim, K. (2000). A New Parameterisation Method for NURBS Surface Interpolation, *The International Journal of Advanced Manufacturing Technology*, 16(11), 784-790, 10.1007/s001700070012. Springer.

Kennedy, J. and Eberhart, R. (1995). Particle Swarm Optimisation, *Proceeding of International Conference on Neural Networks 1995*, Perth, WA , Australia, IEEE, 1942-1948.

Kim, H. (2009). *Multi-Objective Optimization for Ship Hull Form Design*. PhD thesis. George Mason University, Fairfax, VA.

Kuiper, G. (1970). Preliminary Design of Ship Lines by Mathematical Methods. Journal of Ship Research, 14, 52-66. Society of Naval Architects and Marine Engineers (SNAME).

Kuo, C. (1971). *Computer Methods for Ship Surface Design*. London, Longman.

Lee, E. T. Y. (1987). The rational Bézier representation for conics, *Geometric Modeling: Algorithms and New Trends*, 3-19, SIAM.

Lee, E. T. Y. (1989). Choosing nodes in parametric curve interpolation. *Comput. Aided Design.*, 21(6), 363-370, dx.doi.org/10.1016/0010-4485(89)90003-1. Elsevier.

Li,Y., Ng, K. C., Murray-Smith, D. J., Gray, G. J., Sharman, K. C. (1996). Genetic algorithm automated approach to the design of sliding mode control systems: *International Journal of Control*, 63(4), 721-739, Taylor & Francis.

Lim, C. G. (1999), A universal parametrization in B-spline curve and surface interpolation, *Computer Aided Geometric Design*, 16(5), 407-422, DOI: 10.1016/S0167-8396(99)00010-2. Elsevier.

Lowe T. W., Steel J. (2003). Conceptual Hull Design Using a Genetic Algorithm, *Journal of Ship Research*, 47(3), 222-236(15), Society of Naval Architects and Marine Engineers (SNAME).

Lu, C., Yan, L., Ji, Z., Chen, M. (2005). Ship Hull Representation with a single NURBS surface. *Proceeding of 15th International Offshore and Polar Engineering Conference 2005*, Seoul, Korea, ISOPE, 780.

Lu, C., Lin, Y., Ji, Z. (2007). Ship Hull Representation Based on Offset Data with a Single NURBS Surface. *Ship Technology Research*, 54(2), 81-88. Institute of Ship Technology and Ocean Engineering.

Lu, C., Yan, L., Ji, Z., Chen, M. (2008). NURBS Based Ship Form Design Using Adaptive Genetic Algorithm. *Proceeding of 18th International Offshore and Polar Engineering Conference 2008*, Vancouver, BC, Canada, ISOPE, 535

Markus, A., Renner, G., Vancza, J. (1997). Spline interpolation with genetic algorithms. *Proceeding of International Conference on Shape Modeling and Applications 1997*, Aizu-Wakamatsu , Japan, IEEE, 47-54.

Mason, H. B. (1977). *Encyclopedia of Ships and Shipping*. London, The Shipping Encyclopedia Ltd.

Mason, A. (2004). From lines plan to 3d hull form. *Boat Design Forum*. Retrieved July 12, 2010, from http://www.boatdesign.net/forums/design-software/lines-plan-3d-hull-form-4198.html.

Maisonneuve, J. J., Harries, S., Marzi, J., Raven, H. C., Viviani, U. and Piippo, H. (2003). Towards optimal design of ship hull shapes, *Proceedings of the 8th*

International Marine Design Conference (IMDC 2003), Athens, Greece, 1-12.

Meester, R. (2009). Simulation of biological evolution and the NFL theorems. *Biol-Philos*, 24(4), 461–472. Springer-Verlag.

Montgomery, J. (2002). The No Free Lunch Theorems for Optimization: An Overview. *The No Free Lunch Theorems, Evolution and Evolutionary Algorithms*, Retrieved September 27, 2010, from www.martinsewell.com/ evolutionary-computation/nfl/Mont02.pdf.

Munchmeyer, F. C., Schubert, C., Nowacki, H. (1979). Interactive design of fair hull surfaces using B-splines. *Proceedings of the Computer Applications in the Automation of Shipyard Operation and Ship Design*, University of Strathclyde, Glasgow, Scotland.

Nam, J. H. and Parsons M. G. (2000). A parametric approach for initial hull form modeling using NURBS representation. *Journal of Ship Production*, 16(2), 76-89. Society of Naval Architects and Marine Engineers (SNAME).

Nasri, A., Abbas, A., Hasbini, I. (2003). Skinning Catmull-Clark subdivision surfaces with incompatible cross-sectional curves. *Proceedings. of 11th Pacific Conference on Computer Graphics and Applications 2003*. Canmore, Canada, IEEE, 102-111.

Orr, H. A. (2002). Book Review: No Free Lunch. *Boston Review*, 27(3-4). Retrieved September 27, 2010, from http://bostonreview.net/BR27.3/orr.html.

Park, H., Jung, H. B., Kim, K. (2004). A new approach for lofted B-spline surface interpolation to serial contours. *The International Journal of Advanced Manufacturing Technology*, 23(11), 889-895. Springer-Verlag.

Peiyong, X., Xiangqian, D., Ning, Y., (2009). Evolutionary Algorithms for Optimization of Tobacco Leaf Groups Blending. *Proceeding of 10th International Conference on Software Engineering, Artificial Intelligences, Networking and Parallel/Distributed Computing SNPD 2009*. Daegu, China, IEEE, 144-148.

Pérez, F. L., Clemente, J. A., Suárez, J. A., González, J. M. (2008). Parametric Generation, Modeling and Fairing of Simple Hull Lines With the Use of Nonuniform Rational B-Spline Surfaces. *Journal of Ship Research*, 52(1), 1-15. Society of Naval Architects and Marine Engineers (SNAME).

Piegl, L. A. (1991). On NURBS: a survey. *Computer Graphics and Applications*, 11(1), 55-71. IEEE.

Piegl, L. A., Rajab, K., Smarodzinava, V. (2008). Curve interpolation with directional constraints for engineering design. *Engineering with Computers*. 24(1), 79-85. Springer-Verlag.

Piegl, L.A. and Tiller, W. (1996). Algorithm for approximate nurbs skinning. *Computer-Aided Design*, 28(9), 699-706. Elsevier.

Piegl, L.A. and Tiller, W. (1997). *The NURBS Book 2nd edition*. New York, Springer-Verlag.

Piegl, L.A. and Tiller, W. (1999). Cross-Sectional Design with Boundary Constraints. *Engineering with Computers*, 15(2), 171-180. Springer-Verlag.

Piegl, L. A. and Tiller, W. (2000a). Surface approximation to scanned data. *The Visual Computer*, 16(7), 386-395. Springer-Verlag.

Piegl, L. A. and Tiller, W. (2000b). Reducing Control Points in Surface Interpolation. *Computer Graphics and Applications*. 20(5), 70-74. IEEE

Piegl, L. A. and Tiller, W. (2002). Surface skinning revisited. *The Visual Computer*, 18(4), 273-283. Springer-Verlag.

Piegl, L. A., Ma, W. and Tiller, W. (2005). An alternative method of curve interpolation. *The Visual Computer*, 21(1-2), 104-117. Springer-Verlag.

Pinniger, E. (2007). The Ship Modelers Source, The Ship Model Forum. Retrieved September 30, 2010, from http://www.shipmodels.info/mws_forum/viewtopic.php?f=4&t=29082.

Pressley, A.N. (2010). *Elementary Differential Geometry 2nd Edition*, New York, Springer-Verlag.

Priowirjanto, G. H. (2003). *Konsep Dasar Perkapalan*. Jakarta.

Radcliffe, N. J. and Surry, P. D. (1995). Fundamental limitations on search algorithms: Evolutionary computing in perspective. *Lecture Notes in Computer Science*, 1000, 275-291, Springer-Verlag.

Rashedi, E., Nezamabadi-pour, H., Saryazdi, S. (2009). GSA: A Gravitational Search Algorithm, *Information Sciences*, 179(13), 2232-2248. Elsevier.

Rashedi, E., Nezamabadi-pour, H., Saryazdi, S. (2010a). BGSA: Binary Gravitational Search Algorithm, *Natural Computing*, 9(3), 727-745. Springer-Verlag.

Rashedi, E., Nezamabadi-pour, H., Saryazdi, S. (2010b). Filter modeling using gravitational search algorithm, *Engineering Applications of Artificial Intelligence*, In Press. Elsevier.

Rawson, K.J., Tupper, E.C. (2001). *Basic Ship Theory (5th Edition).* Elsevier.

Rhinoceros®. (2001). Fairing a Hull Surface 4.0. *Rhino User manual*.

Robert, T. (1980). *Ship Design and Construction*. The Society of Naval Architects and Marine Engineers, New York.

Rogers, D. F. (1977). B-Spline Curves and Surfaces for Ship Hull Definition.*Symposium of Computer-Aided Hull Surface Definition SCAHD 1977*. Annapolis, Maryland, New York, Soc. of Naval Architects and Marine Engineers, 79-96.

Rogers, D. F. and Steven, G. S. (1980). B-spline Surfaces for Ship Hull Design. *Proceedings of the 7th annual conference on Computer graphics and interactive techniques 1980*, Seattle, Washington, US, ACM, 211-217.

Rogers, D. F., Steven, S., Francisco, R. (1983). Ship Hulls, B-Spline Surfaces, and CAD/CAM. *IEEE Comput. Graph. Appl.*, 3(9), 37-45.

Rogers, D.F. (2001). *An introduction to NURBS: with historical perspective*. San Francisco, Morgan Kaufmann Publishers.

Roy, R., Jared, G., Mussa, R. (2002). Curve and surface optimization within the CAD/CAM environment. *Journal of Engineering Design*, 13(2), 121-139. Taylor and Francis.

Ryan, N. (2006). Editable 3D Nurbs model on the Internet - An investigation in 3D technologies for mass customisation which can be applied in the Shoe industry. Master Thesis. The Oslo School of Architecture and Design. Oslo.

Sapidis, N. S. (1994). *Designing Fair Curves and Surfaces: Shape Quality in Geometric Modeling and Computer-Aided Design*. Philadelphia, Society for Industrial and Applied Mathematics.

Sariöz, E. (2006). An optimization approach for fairing of ship hull forms. *Ocean Engineering*, 33(16), 2105-2118. Elsevier.

Sarioz, K. (2009). Computer Aided Ship Design. *Lecture Notes on Ship Design*, 2.5-2.8.

Schutte, J. F. and Groenwold, A. A. (2005). A Study of Global Optimization Using Particle Swarms. *Journal of Global Optimization*, 31(1), 93-108, Springer-Verlag.

Seidenberg, L. R., Jerard, R. B., Magewick, J. (1992). Surface Curvature Analysis Using Color. *Proceedings of the 3rd conference on Visualization 1992*, Boston, Massachusetts, IEEE, 260-267.

Shamsuddin, S., Ahmed, M., Smian, Y. (2006). NURBS skinning surface for ship hull design based on new parameterization method. *The International Journal of Advanced Manufacturing Technology*, 28(9), 936-941. Springer-Verlag.

Shene, C. K., (2003). CS3621 Introduction to Computing with Geometry Notes. *Introduction to Computing with Geometry Notes*. Retrieved July 12, 2010, from http://www.cs.mtu.edu/~shene/COURSES/cs3621/NOTES/ .

Shi, Y. and Eberhart, R.C. (1998). A modified particle swarm optimizer, *Proceedings of the IEEE International Conference on Evolutionary Computation 1998*. Piscataway, NJ, IEEE, 69–73.

Sorum, A. (2007). What is the Best Hull Shape?. *Issues Involved with Vessel Performance Design*. Retrieved July 12, 2010, from www.suite101.com/ content/what-is-the-best-hull-shape-a29981.

Standerski, N. B. (1989). The generation of ship hulls with given design parameters using tensor product surfaces. *In Theory and practice of geometric modeling*, 65-79, Springer-Verlag New York, Inc.

Sun, Y. H., Tao, Z. L., Wei, J. X., Xia, D. S. (2010). B-Spline Curve Fitting Based on Adaptive Particle Swarm Optimization Algorithm. *Applied Mechanics and Materials*. 20(23), 1299-1304, Trans Tech Publications.

Tahara, Y., Tohyama, S., Katsui, T. (2006). CFD-based multi-objective optimization method for ship design. *International Journal for Numerical Methods in Fluids*, 52(5), 499-527. John Wiley & Sons, Ltd.

Tosaka, (2008). Ship lines (3D design). Wikipedia. Retrieved October 1, 2010, from http://commons.wikimedia.org/wiki/File:Ship_lines_(3D_design).PNG.

Tiller, W. (1992). Knot-removal algorithms for NURBS curves and surfaces. *Computer-Aided Design*, 24(8), 445-453. Elsevier.

Ventura, M. (2009). Geometric Modeling of the Hull Form, *Ship Hull Design Lecture Notes*, Retrieved March 12, 2010, from www.mar.ist.utl.pt/mventura/ Projecto-Navios-I/EN/SDI-1.5.3-Hull%20Geometric%20Modeling.pdf

Versprille, K. (1975). *Computer aided design applications of the rational B-spline approximation form*. PhD thesis, Syracuse U.

Wall, M. (1996). Introduction to Genetic Algorithms.*Lecture notes presentation*, Retrieved September 20, 2010, from http://lancet.mit.edu/~mbwall/ presentations/IntroToGAs/.

Wang, H. and Zou, Z. (2008). Geometry modeling of ship hull based on non-uniform B-spline. *Journal of Shanghai Jiaotong University (Science)*, 13(2), 1007-1172, Shanghai Jiao Tong University Press.

Wang, W. and Zhang, H. (2009). Algorithm for Approximate NURBS Surface Skinning and Its Application. *Proceeding of 11th International Conference on Computer-Aided Design and Computer Graphics 2009*. Huangshan, IEEE, 312-317.

Wang, W., Zhanga, H., Park, H., Yonga, J., Paul, J., Sun, J (2008). Reducing control points in lofted B-spline surface interpolation using common knot vector determination. *Computer-Aided Design*, 40(10-11), 999-1008. Elsevier.

Wen, A. S., Shamsuddin, S. M., Samian, Y. (2005). Ship hull fitting using NURBS. Paper presented at the Computer Graphics, Imaging and Vision: New Trends, 2005.

Wen, A. S., Shamsuddin, S. M., Samian, Y. (2006). Optimized NURBS Ship Hull Fitting using Simulated Annealing. *Proceeding of International Conference on Computer Graphics, Imaging, and Visualisation2006*, Sydney, Australia, IEEE, 484-489.

Wen, A. S. (2006). *Optimization of Ship Hull NURBS Surface Fitting using Simulated Annealing*. Master thesis. Universiti Teknologi Malaysia, Skudai.

Westlake, P C and Wilson, P A. (2000). New conformal mapping technique for ship sections. *International Shipbuilding Progress*. 47(449), 5-22. IOS Press.

Wolpert, D. H. and Macready, W. G. (1995). *No Free Lunch Theorem for Search*. Technical Reports SFI-TR-95-02-010. Santa Fe Institute, Sante Fe, USA.

Wolpert, D. H. and Macready, W. G. (1997). No Free Lunch Theorems for Optimiztion. *IEEE Transactions on Evolutionary Computation*, 1(1), 67-82. IEEE.

Wolpert, D. H. (2001). The supervised learning no-free-lunch Theorems, *Proceeding of 6th Online World Conference on Soft Computing in Industrial Applications*, On the Internet (World Wide Web), vision.fhg.de/wsc6, WFSC, 25-42.

Woodward, C. D. (1987). Cross-sectional design of B-spline surfaces. *Computers & Graphics*. 11(2), 193-201, Elsevier.

Woodward, C.D. (1988). Skinning techniques for interactive B-spline surface interpolation. *Computer-Aided Design*. 20(8), 441-451, Elsevier.

WordIQ (2010). Ship Definition. *Dictionary and Encyclopedia Directory*. Retrieved July 12, 2010, from http://www.wordiq.com/definition/Ship.

Zhang, P., Zhu, D., Leng, W. (2008). Parametric approach to design of hull forms. *Journal of Hydrodynamics, Ser. B*. 20(6), 804-810. Elsevier.