ENGINEERS AUSTRALIA

6th Australasian Congress on Applied Mechanics

	model fixed at both ends for flow-induced instability analysis	Investigations of Friction and Wear Phenomena in Water-Lubricated Bearings	Fiber Reinforced Composites during Stamp Forming	Condition Monitoring
14:05 to 14:25	Jarrad S. Kapor [1041] Fluid-Structure Interaction Using Mesh-Free Modelling	Ronghao Bao [1115] From Stokes roughness to Reynolds roughness: a perturbation characterisation	Phuc Nguyen [1121] Investigation of Thermo-Mechanical Properties of Thermal Barrier Coatings Fabricated using the Slurry Spray Technique	Mohsen Askari [1201] Multi Objective Optimal Placement of Structural Control Actuators
TOPIC		Machine Dynamics		Computational Mechanics
14:25 to 14:45	Ben Hoea Tan [1130] Hydroelastic Stability of an Inhomogeneous Flexible Panel in a Uniform Mean Flow	Ray Malpress [1180] Assessment of an eccentric link in the connecting rod of a spark ignition engine intended for variable compression ratio operation	Garry Leadbeater [1226] Processing and properties of porous Ti-Nb-Ta-Zr alloy for biomedical applications using the powder metallurgy route	F. Kolahan [1254] Modeling and optimization of the electron beam welding process using statistical approaches
14:45 to 15:05	Mohammad Reza Mobinipouya [1138] A promising avenue for the intensification of turbulent free convection in square cavities using an adequate selection of binary gas mixtures	F. Ding [1189] Modelling and Dynamic Analysis of a Heavy Duty Truck with Rear Tandem Axle Bogie Suspension System	Y C Lam [1005] Surface roughness, hardness and strength of an aluminum mold fabricated by hot embossing	Mohammad Reza Mobinipouya [1139] Deviation of the calculated vapor and liquid density of refrigerant fluids at different temperatures and pressures using aforementioned equations of state from literature data
15:05 to 15:30	Afternoon Tea Break			
SESSIONS	NINE			
ROOM NO	5	6	7	8
TOPIC	Fluid Structural Interaction Session Chair: Dr. Mark Pitman	Machine Dynamics Session Chair: Dr Brian Boswell	Structural Mechanics Session Chair: Prof Tongxi Yu	Computational Mechanics Session Chair: Dr James Jewkes
15:30 to 15:50	Novak S. J. Elliott [1268] Wave propagation in an elastic waveguide: fluid-structure interactions in a spinal disease	Vladis Kosse [1090] Advanced mathematical modelling and experimental investigation of new torque arms for shaft-mounted drives	Dong (Tracy) Ruan [1188] Experimental investigation of the lateral crushing behaviour of short sandwich tubes	M. H. Abolbashari [1045] Topology optimization of continuum structures with elasto-plastic behaviour using evolutionary structural optimization based on stress and stiffness criteria
TOPIC	ACOUSTICS			
15:50 to 16:10	Daniel R. Wilkes [1018] Application of the Fast Multipole Boundary Element Method to Underwater Acoustic Scattering	Kazem Abhary [1233] A new analytical method for kinematic analysis of planar mechanisms	Bijan Samali [1195] Adaptive Neuro-Fuzzy Modelling of a high-rise structure equipped with an Active Tuned Mass Damper	F. Kolahan [1252] Optimization Of Process Parameters In Laser Welding By Simulated Annealing Algorithm
16:10 to 16:30	Jie Pan [1223] Near field sound radiation from a finite-sized loudspeaker in a room	Zhongwei Wang [1262] The Development of Lumped Mass Dynamic Modeling Methods of Planetary Gearbox for Fault Detection and Diagnosis	M.H. Abolbashari [1071] Analytical solution of functionally graded plates with any combination of clamped and simply supported boundary conditions under transverse mechanical loading	F. Kolahan [1251] Optimizing of fair curves based on the strain energy criterion using Tabu Search algorithm
16:30 to 16:50		Ding Fei [1184] Study on bifurcation characteristics of front wheel self-excited shimmy	M.H. Abolbashari [1003] Overall Deflection Minimization of Structures Using Morphing Evolutionary Structural Optimization Method	
16:50 to			M.H. Abolbashari [1046]	

6th Australasian Congress on Applied Mechanics, ACAM 6
12-15 December 2010, Perth, Australia

Optimization of fair curves based on the strain energy criterion using Tabu Search algorithm

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Abstract: Nowadays, reverse engineering is widely used in design and manufacturing industries. In order to analyze or modify a design, data points are collected from the workpiece surface using cloud points system. The curves are then constructed by approximating through the data points. Such approximated curves could contain some errors that may reduce the accuracy of the product being designed. In this paper, two optimization procedures are developed to reduce the noises of extracted data points and to optimally determine the corresponding data point parameters. This would allow achieving the best possible B-Spline fit. In the first stage, using discrete geometry and strain energy criterion, data points are repositioned to obtain fair points. The parameters of data points are then optimized to approximate the fairest curve. This is also done based on the strain energy criterion. In both stages, Tabu Search (TS) algorithm is employed as the optimization procedure. An illustrative example is presented to show the performance of the proposed procedure.

Keywords: CAD, curve fairing, Tabu Search algorithm, strain energy.

1 Introduction

In any CAD system, curves are needed for analyzing and modifying the design. One way of creating curves is to use data obtained from cloud point systems. However, the constructed curves may have errors due to the noises in the digitized data points. These noises may result in unacceptable results in modifying a design. The process of eliminating errors is known as *"curve fairing"* which is a fertile research area. The ability of fairing, to the large extends, depends on how curves approximate the real data of cloud points. One of the most common and widely used curve generation procedures is the parametric B-Spline. There are four methods for fairing B-Spline curves; namely, repositioning control points, changing the weights of control points in rational B-Spline curves, re-positioning the data points and modifying knots and data parameters [1].

The construction of a system for the design of fair curves requires a criterion to assess whether a curve is fair. Generally, the fairness of a curve is closely related to the way the curvature varies along the curve [2]. Generally, large and frequent fluctuations in curvature are not desirable. Usually, when the curvature is monotonic, the result is more acceptable. Sapidis [3] proposed a well-known criterion for a fair curve as follows: "a curve is fair if the curvature plot is continuous and is as close as possible to a piecewise monotone function with as few monotone pieces as possible". In this paper, re-positioning the data points and modifying data parameters have been employed to achieve a fair curve. Due to applying TS algorithm, both optimizations have been performed based on strain energy criterion. Finally, comparing with Sapidis criterion, performance of proposed optimization procedure is shown.

2 B-Spline curve approximation

B-Spline is one of the most practical curves for industrial applications, due to its flexibility, desirable continuity and excellent geometric manageability. This curve is defined parametrically where a set of points controls its overall shape. Points on the B-Spline curve are obtained from equation 1.

$$C(u)=\sum_{i=0}^{h} N_{i,p}(u)P_i \tag{1}$$

Where C is a given point on the curve, u is the parameter of the curve, $N_{i,p}$ is the basic function (p refers to the degree of curve) and P_i is the set of control points. To measure how well a curve approximates a given data points, the concept of error distance is used here. The error distance is the distance between a data point and its corresponding point on the curve. Thus, if the sum of these error distances is minimized, the curve would follow the shape of the data points closely. The error function is defined as *Mean Least Square* given by Equation 2.

$$MLS = \sum_{k=1}^{n-1} \left| D_k - C(t_k) \right|^2 \tag{2}$$

In the above, D_k is the k^{th} data point with the corresponding parameter t_k. By simultaneously solving the set of equations the corresponding control points, P_i, can be found. In this way, the curve closely follows the trend of control points. Therefore, in process of curve approximation, the final shape of the B-Spline curve follows the data points.

3 Fairness Metric

As mentioned earlier, if the curvature of curve is continuous or vary monotonically, the curve is said to be fair. By plotting the curvature variations along the curve, fairness can be visually analyzed. However, re-positioning the data points and modifying data parameters would result in an extremity large solution space. Therefore, heuristic algorithms, such as Tabu Search (TS) can be used to solve such large problems. The first step in implementing this algorithm is to define a measure of performance (objective function) in the form of a quantitative criterion. In this study, strain energy is used as the criterion for assessing the fairness metrics of curves. Using this notion, the design of fair curves is defined physically rather than mathematically. For instance, if an elastic beam has many concentrated forces and it passes through several points, the beam is said to have the fairest possible curve with minimum strain energy [4]. In this way, if strain energy of the curve is minimized the curve is the fairest. The strain energy of a curve may be defined as follow:

$$U = \int_0^l (k(s))^2 \, ds \tag{3}$$

Where l is the length of the curve and $k(s)$ is the value of the curvature over the length s.

By minimizing the total strain energy, a curve with the highest possible fairness may be achieved. In this paper the strain energy has been used, as the fairness criterion, both in fairing data points and in optimizing their corresponding parameters. In the first stage of optimization, using discrete geometry, the strain energy of data points are calculated [1]. In the next phase, the strain energy of B-Spline is calculated numerically and used as the evaluation criterion. If the data points and their associated parameters have the minimum strain energy, the curve is the fairest.

4 Optimizing procedure

Tabu Search (TS), first introduced by Glover [5], is an iterative neighborhood search capable of escaping from local optima. It involves the exploration of solution space through the iterative investigation of neighborhood solutions. The search process starts from a feasible solution and moves stepwise towards a neighboring solution. After a number of moves an optimal or near-optimal solution may be obtained. To make a move, a set of neighboring solutions around the current solution is generated and evaluated based on the objective criterion. Then, a move is made to the best allowable solution in the neighborhood. The main advantage of TS is its ability to escape from local optima by accepting non-improving solutions. Another important feature of Tabu Search is the use of tabu list as a short term memory. A tabu list contains a number of immediate previous moves which are not allowed at the current iteration. The use of tabu list alleviates the cycling problem since the search is prohibited from returning to any of the previous moves specified in the tabu list. Following each move, the tabu list is updated by adding the new move and removing the oldest move from the list. The details of Tabu Search and its refined versions are well documented in the literature [6].

In CAD related applications, to achieve a fair B-Spline curve data points and their corresponding parameters should properly be determined. In this study, TS is first applied to make the data points fairer. To generate a neighbouring solution during the search, a number of data points are randomly selected and their positions are slightly changed. This procedure is repeated until all solutions in the current neighbourhood are generated. The number of data points and the number of neighbour solutions are pre-specified. Then, the strain energies of all solutions in the current neighbourhood are compared. A move is then made to the best solution, provided it is not in the tabu list. The algorithm is stopped when the termination criteria (in this case number of iterations) is reached.

The same logic is employed for the second phase of optimization in which parameters of faired data points are optimally determined. In this phase, to create a neighbor a pre-determined number of data parameters are selected and their values are slightly changed. The strain energy is also used here for solutions evaluation.

5 Results and discussions

In this section, an illustrative example is provided to show the performance of the proposed two-phased optimization procedure. Let us consider a B-Spline for letter S consisting of 100 points extracted from the cloud points. This problem is analyzed under four different scenarios. For comparison purposed, in all cases curvatures (dotted lines) are plotted along the B-spline curves (solid lines). These cases are described as follows:

Case a: In this case, raw data points and chord length parameterization are used to approximate the curve (Figure 1.a). No manipulations are performed on data obtained from cloud points. As show, various types of inaccuracies and noises make the curvature to have large and frequent fluctuations.

Cases b and c: In case b, data points have not been modified, but using TS algorithm the corresponding parameters have been optimized. By the same token, in case c only data points have been modified and no optimization is performed on the parameters. Although curves in cases b and c are fairer, there still exist large amount of noises and fluctuations.

Case d: In this scenario, the example problem has gone through both phases of optimization. In the first step the data point are modified to reduce their noises. The second stage involves optimizing the data parameters that further enhances the fairness of the curve. As show, this scenario is superior to all previous cases and result in a smooth noise free B-spline. It can be seen that the curvature is close to a piecewise monotone function with as few monotone pieces. Hence it can be said that the proposed algorithm conforms to the Sapidis criterion to design a fair curve.

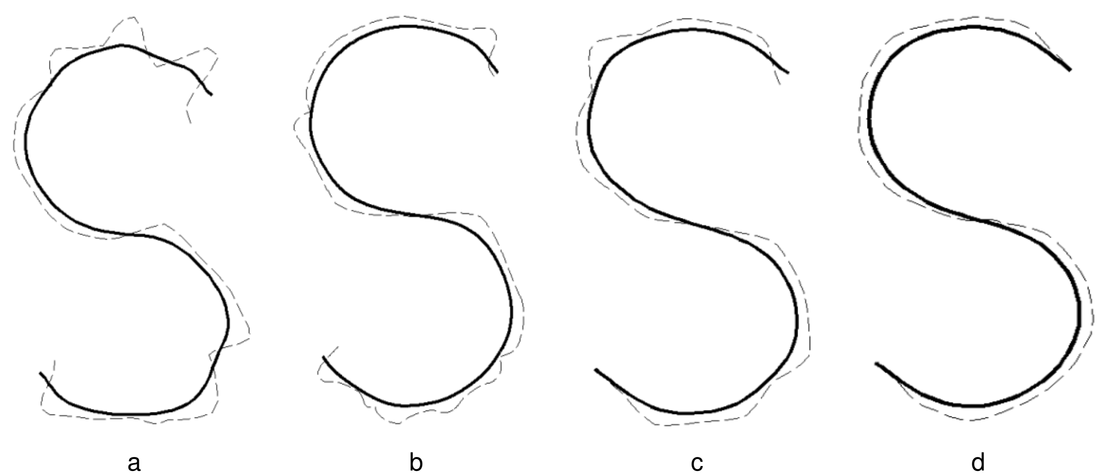

Figure 1: Curvature plot of four investigated states

The convergence of algorithm towards the exact curve by optimizing the data points and their corresponding parameters is shown in Figure 2.a and Figure 2.b, respectively. So, it can be said the exact curve can be closely approximated, applying proposed algorithm.

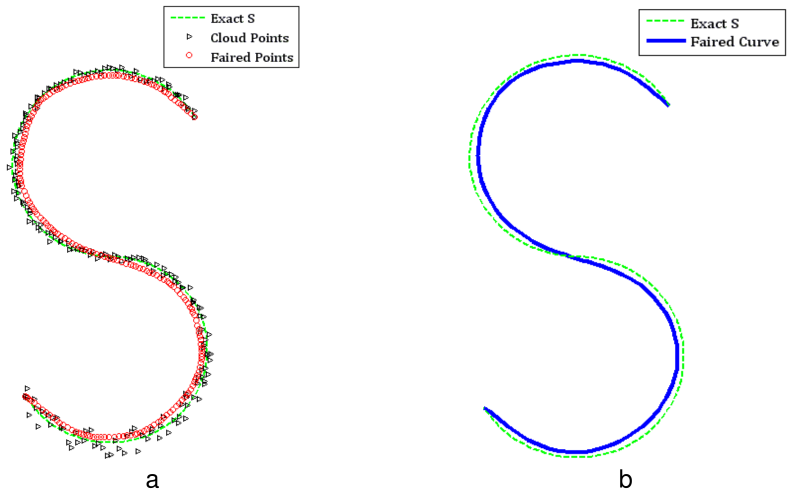

Figure 2: Algorithm convergence in optimizing data and corresponding parameters

6 Conclusions

The main interest in many engineering applications is to determine the values of design parameters in order to obtain a desired output. Producing fair curves has always been a critical issue in reverse engineering of industrial parts. The accuracy of a B-spline curve depends on the quality of data points and their corresponding parameters. However, due to the very large number of possible solutions, enumeration based methods are inadequate in finding accurate approximations. In this regard, intelligent search algorithms such as TS are capable to provide near optimal solutions within reasonable computational times.

In this paper, using strain energy criterion and Tabu Search algorithm, a two-stage procedure has been developed to enhance the fairness of the curve. In the first stage, raw data, extracted from cloud points, are modified. This is done through noise reduction and data modifications. Then, final curve can be approximated through the fair points with the optimized corresponding parameters. Computational results show that optimization based on the strain energy would also satisfy Sapidis criteria as fairness metrics for curves.

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