The Product Innovative Design Methodology Integrating Reverse Engineering with Optimization — A Case Study on Automotive Styling

H.W. Xiong, J. Xu, C.X. Xu, M. Pan
Faculty of Electromechanical Engineering
Guangdong University of Technology
China

***Abstract*-In the styling phase of a product design, it's difficult to meet aesthetic and performance requirements simultaneously. An innovative design methodology integrating reverse engineering (RE) with optimization is illustrated to settle such a problem. In the field of automotive styling, the stylist's aesthetic intent is usually expressed by a clay model, and on the other hand, the aerodynamic performance may be ignored. Reverse engineering is used to convert a clay model to a digital model, which is then transferred to computational fluid dynamic (CFD) software to evaluate the aerodynamic performance. A variety of new design samples may be generated using free form deformation (FFD) deduced by a simple control polygon with few parameters, and the response surface method (RSM) is adopted to explore the relationships between these few parameters and two aerodynamic response variables. The final optimized solution can be found through a multi-objective genetic algorithm. A detail example is presented to verify the method.**

Keywords-reverse engineering; product innovative design; automotive styling

I. Introduction

Computer-aided design (CAD) is an important tool in many applications, and is used together with other software, such as Computer-aided engineering (CAE) and Computer-aided manufacturing (CAM), to increase the productivity of the designer, improve the quality of design. Although there are many CAD systems existed, in the styling phase of a product design, it's still a difficult problem to obtain a shape meeting aesthetic and physical performance requirements simultaneously.

In the field of automotive styling, a clay model is usually used to express the stylist's aesthetic intent, and the physical performance is tested in a wind tunnel. After a series of iterations, a final model can be obtained in an expensive and inefficiency way. To reduce the experiment cost, some computational fluid dynamic (CFD) software substitutes for physical wind tunnels with virtual experiment.

CAE based optimization is a relatively new direction of design methodology, and can improve product performance efficiently. There are two difficulties to overcome in current problem. One is that, in the automotive industry, the number of shape parameters is too large to find a workable algorithm. Another is that, the performance optimization result may destroy the aesthetic aspect.

In this paper, an innovative design methodology integrating reverse engineering (RE) with optimization is presented to settle such a problem. RE is used to convert a clay model to a spline-based surface model capturing stylist's intent. The digital model can be transferred to computational fluid dynamic (CFD) software to evaluate the aerodynamic performance. A simple control polygon is used to generate free form deformation (FFD) of the spline model, and three control points of the polygon are selected to move in specialized directions and ranges to maintain aesthetic aspect. A variety of new design samples may be generated with few parameters and the response surface method (RSM) is adopted to explore the relationships between these parameters and two aerodynamic response variables. The final optimized solution can be found through a multi-objective genetic algorithm.

The section 2 of the paper presents some related works, and the integrated innovative design methodology is discussed in section 3.The conclusion is drawn in section 4.

II. Related works

There are many works on reverse engineering [1-2]. Some researches talk about measurement devices, and others deal with surface reconstruction problem. A few of practice RE examples are also reported.

There are more papers about CAE and optimization [3-4,6], because they are foundation problems in engineering design.

In paper [5], Ye proposed a innovative design strategy based on reverse engineering. The main points of the paper are three different RE methods, all of which can't deal with complex objects such car body, and the optimization method can only resolves simple problem.

In this paper, we propose a new innovative design workflow in a typical field of RE applications. Clay model is always used to express the stylist's intent. Through RE method, the clay model can be converted to a digital model and evaluated by some CAE software. The key problem turns out, if the evaluation result is poor, how to improve it and maintain the aesthetic aspect simultaneously. For a simple mechanic component, there is no problem, because the number of parameters to control the shape is few. But for a car body, there are thousands of parameters to control the complex geometry. Nowadays, as far as we know, there is no example reported to optimize a clay car body automatically.

III. THE PRODUCT INNOVATIVE DESIGN METHODOLOGY INTEGRATING RE WITH OPTIMIZATION

The proposed methodology consists of three main modules: RE module, FFD module and CAE-based optimization module.

A commercial software ImageWare is used in RE module to reconstruct the CAD model from the measured data, as showed in Fig.1. The point clouds are first segmented into patches, and then control curve networks for each patch are extracted, which are used to obtain final spline-based surfaces. Some surfaces are further trimmed to represent the real object.

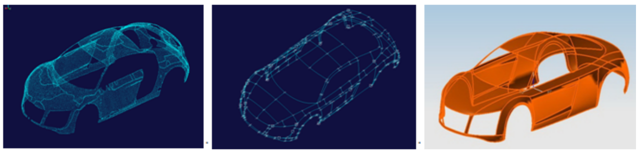

FIGURE I. THE REVERSE ENGINEERING PROCESS.

The modified CAD model reconstructed from RE module can be transferred to Fluent, famous computational fluid dynamic (CFD) software, to evaluate the aerodynamic performance of the clay model, as showed in Fig.2. Two important performance parameters for a car body can be generated from the simulated flow distribution, named lift coefficient and drag coefficient respectively. For a perfect design, the two coefficients ought to be minimized.

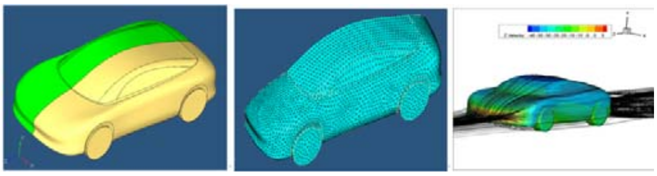

FIGURE II. THE CAE PROCEDURE

To minimize the lift coefficient and drag coefficient is not a trial task, because the number of parameters to represent the shape is too large to find a workable algorithm. In this paper, we design a simple polygon block to control the car body, as showed in Fig.3. The polygon block controls the digital model by free form deformation (FFD). Moving one vertex of the polygon will cause a smooth deformation of the shape. Three control points of the polygon are selected to move in specialized directions and ranges to maintain aesthetic aspect according to the stylist's suggestions. The front end, front door and rear door are controlled by the three points respectively. A variety of new digital models may be generated with few parameters by this FFD method.

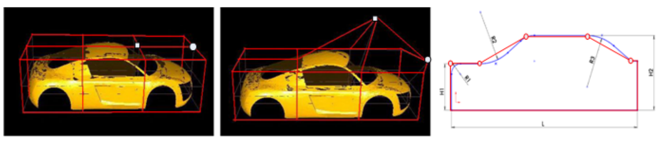

FIGURE III. THE FFD MODULE

Response surface methodology (RSM) is used to optimize the initial digital model. In statistics, RSM explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. In this paper, the explanatory variables are moving distances of the three control points, and the response variables are lift coefficient and drag coefficient. A design of experiments (DOE) table is generated by Sobol sequence method, and the response function is approximated through Kriging algorithm. All procedures are integrated within optimization software named modeFRONTIER. The whole workflow is showed in Fig.4.

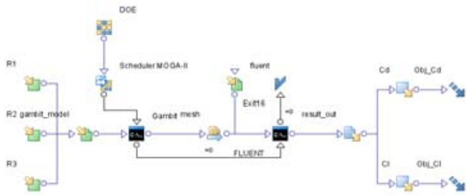

FIGURE IV. THE WORKFLOW OF THE CAE-BASED OPTIMIZATION

This paper deals with the multiple response problems. Multiple response variables create difficulty because what is optimal for one response may not be optimal for other responses. To obtain perfect the car body shape with minimizing lift coefficient and drag coefficient, a multi-objective genetic algorithm is adopted.

To verify the proposed method, we test on a 1:20 clay model. Fig.1 Fig.2 and Fig.3 show some intermediate results, and the final optimized result is showed in Fig.5. In this test, the initial styling intent is captured by RE module, and the aerodynamic performance is improved by following optimization module. At the same, the aesthetic aspect is maintained.

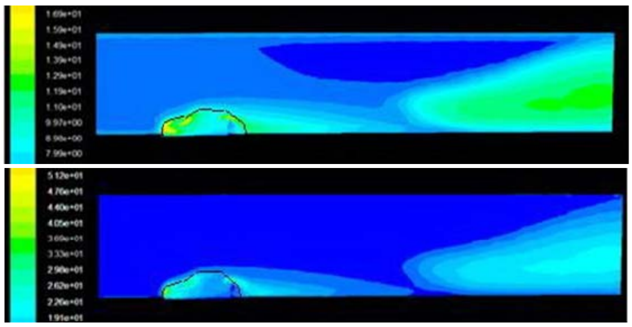

FIGURE V. THE COMPARED AERODYNAMIC PERFORMANCE BETWEEN INITIAL AND OPTIMIZED CAR BODY

IV. CONCLUSIONS

In this paper, we present an integrated innovative design methodology by integrating reverse with CAE-based optimization, which can capture the aesthetic intent and search best physical performance simultaneously. The whole workflow is illustrated by a case study on automotive styling, and the effect of the method is verified on a real clay model.

ACKNOWLEDGEMENTS

This research was funded by National Natural Science Foundation of China grant (51375096).

REFERENCES

[1] Hoppe H., DeRose T. & Stuetzle W., Surface Reconstruction From Unorganized Points. *Computer Graphics*, 26(2),pp.92-98,1992.

[2] Barbero B.R., The Recovery Of Design Intent In Reverse Engineering Problems. *Computer Industrial Engineering*, 56(4), pp.1265 -1278, 2009.

[3] Park H.S. & Dang X.P., Structural Optimization Based On CAD–CAE Integration and Metamodeling Techniques. *Computer Aided Design*, 42(10),pp.889–902, 2010.

[4] Merkel M.& Schumacher A., An Automated Optimization Process for a CAE Driven Product Development. *Journal of Mechanical Design*,125(4),pp.694-700,2004.

[5] Ye X.Z., Liu H.Z. & Chen L., Reverse Innovative Design — An Integrated Product Design Methodology. *Computer Aided Design*, 40(7),pp.812-827,2008.

[6] George E.P. & Norman R., *Response Surfaces, Mixtures, and Ridge Analyses*, John Wiley & Sons: New Jersey,pp.1-16,2007.