Using Interactive Genetic Algorithm to Generate New Vehicle Styling Brand Elements with Feature Lines

A Case Study of Micro-car Design in China

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Abstract: Vehicle's appearance or styling plays a key role in its brand identity. In the paper, we introduced a design research case by using interactive genetic algorithm method to build up vehicle styling brand elements in designing of one Chinese local vehicle – Changan Benben. Based on the styling brand elements acquired in the brand elements research on existing vehicles of Changan, interactive genetic algorithm was adopted to generate Changan Benben new styling brand elements in one typical feature line – lateral contour line. The generated feature lines were applied in the new Changan Benben design practice and achieved initial success.

Key words: Generative design, Interactive Genetic Algorithm, Vehicle Styling, Brand Elements, Feature Line

1. Introduction

A clear and well-defined brand identity plays an important role of business success [4, 11]. Brand identity is a combination of factors, in which appearance or styling of products expresses the key value of the brand with their forms [29]. Vehicle is one of the typical mass-market products with long R&D period and considerable investment. The consistent vehicle form and styling can help vehicle manufactures to keep and reinforce the brand identity while an individual vehicle evolved with advanced technology, design trends, users' preference, and so on. Therefore, styling brand elements of vehicle (also known as "brand DNA") have become a key issue to support all participants in the design process [9, 19].

However, in existing vehicle styling design practices, designers create new styling mainly relying on previous experience or intuition and there was little support for designers in the designing of current or future appearance with respect to brand identity [19]. Meanwhile, in many new developing vehicle manufactures, such as the most local vehicle manufactures in China, the brand history is short and there are not clear historical styling identity elements, which can guide the design practices. In such China vehicle manufactures, although some of the vehicles were with good designing styling and well-acceptance of users, the designers and stakeholders do not understand what are the brand elements of styling because they have not enough experience on design branding practice and they have to explore larger design space to conduct branding design [28]. Therefore, using computer technologies(such as genetic algorithm) to support the brand design in China vehicle manufactures is a possible solution to solve such problems.

In the paper, we will introduce a design research case by using interactive generative design method to build up vehicle styling brand elements in a micro-car designing of one Chinese local vehicle manufacture: Changan. In

2011, Cahngan's micro-car Benben's sales number in China were reaching 90 thousand per year, which held the 5th position of the vehicle sales number in China [8]. The design team of Benben wanted to build up Benben's brand identity in vehicle styling and appearance to guide the future design based on the existing success of Benben In the study, we firstly analyzed the styling elements and concluded the key styling brand elements of Changan Benben. Then, we used interactive genetic algorithms to generate vehicle styling brand elements with one typical feature line – lateral contour feature line. Finally, the generated styling brand feature lines were successfully applied in new Changan Benben design practice.

2. Related Work

2.1 Genetic Algorithm and Generative Design

Genetic algorithm is an evolutionary technique in artificial intelligence, which is used in computing to find exact or approximate solutions to search and optimize problems [1]. A genetic algorithm consists of three basic stages: choosing and coding initial population, seting up threshold and operator, evaluating the fitness of each individual in the population [3]. Interactive evolutionary algorithm is one of the evolutionary algorithms that use human intelligence in the process of generation [27]. Interactive evolutionary algorithm is usually applied to domains where it is hard to design a computational fitness function, for example, evolving images, music, artistic designs and forms to fit users' aesthetic preference [13].

Generative design is a paradigm for design research, which uses computational capabilities to support human designers to achieve the efficiency, cost reduction, optimization, accuracy and consistency of design process[22]. There were some generative design approaches in the product styling and appearances. Dorin built up an Aesthetic Fitness and Artificial Evolution algorithm to select imagery [7]. Ding and Gero used genetic algorithm to emerge of representation styles in environmental planning [6]. Soddu built up a generative design system in architecture and product design [24]. As Oxman concluded, generative technology has become a new approach in the design research of digital age [17].

2.2 Vehicle Shape Decomposition and Key Feature Line

To vehicle or other complex product, shape decomposition is a tool or method to help designers and related stakeholders to understand styling, form, aesthetics attributes and design itself, which based on shape grammar in architecture, engineering and design field [20, 23]. From 2001, Pugliese, McCormack, Cagan, Vogel investigated the shape grammar of vehicles and motocycles by decomposing the vehicle styling to aesthetics elements [15, 16, 18]. Karjalainen explored the aesthetics properties of Toyota's cars styling and brand through visual decomposition [10]. Liem, Abidin and Warell studied the recognition of aesthetics features of vehicle [14]. Ranscombe, et al proposed a series of visual decomposition strategies and approaches for vehicle images [19]. Chiu, Fan and Yang performed Support Vector Regression (SVR) to incorporate the psychological response of customers into the design of shape variables for green cars [5].

In addition, based on the shape grammar, our research team captured and coded 20 key feature-lines and decomposed them into 3 categories: the main feature-line, the transitional feature-line and the append feature-line. [30]. Based on these key feature lines, an emotional genetic model was built to generate new automobile form in concept design [26].

In this paper, on the basis of the previous studies, we tried to use interactive genetic algorithms to generate new vehicle styling brand elements with feature lines in a micro-car design of China. In contrast to our previous studies, the study focused on the styling elements on brand identity instead of just the aesthetic ones.

3. Research Approach

The research consisted of two main parts: styling brand elements research with capturing Changan Benben brand elements and interactive generative design with one typical feature line.

3.1 Styling Brand Elements Research

The purpose of the styling brand elements research was to capture Changan Benben styling brand elements, which were the basis of the following generative design.

Different from the current brand elements studies, such as the studies of General Motors [16] and Toyota [10], the brand history of Benben is just about 4 years long and with only one vehicles in Chinese market, so that it is hard to directly conclude the styling brand elements from brand history and existing vehicles' styling. Therefore, we captured the brand elements with integrated means, which consisted of aesthetic elements tracing of Changan's existing vehicles, brand feature lines survey from experienced designers and brand elements representative sketching study from designers of Benben micro-cars.

As the basis of the study, the edges and outlines of four Changan vehicles were traced firstly from the Alias and UG digital models by using B-spline curves tracing method [20], in which 37 aesthetic feature lines were identified. The aesthetic feature lines provided the basis of the following two researches.

In brand feature line survey, we adopted the widely used investigation method in social science domain - expert survey [2]. The brand feature line expert survey was proposed based on the 37 aesthetic feature lines displaying decomposed images of front, side, rear and perspective views of Changan vehicles. Seven car styling designers with at least 5-year experience participated in the survey. First, the designer experts were asked to review the eight different brand typical micro-cars in Chinese market. Then, the experts highlighted the featured Changan existing 4 vehicles brand outlines and described the outline with texts. After eliminating the repeated feature lines of the eight expert surveys, 15 feature lines and their shape grammars were identified as the styling brand elements in the study. Figure 1 showed some brand feature lines identified from the four Changan existing 4 vehicles.

Figure 1. Some Brand Feature Lines of the Four Changan Vehicles

In the representative sketching study, we used the method of feature lines capturing experiment in our former related study [30]. The experiment captures the features-lines and their shape grammars with a task of vehicle representative sketching and design concept sketching. Changan Benben's design director and other two main designers were invited to participate in the experiment and asked to describe the styling brand elements series micro-cars by their sketches. For example, Figure 2 is some of the sketches from Tinting Hu, the designer of Changan Benben. Twelve brand elements and their shape grammars were found in Hu's sketches. The experiment identified 17 feature lines, in which 13 ones were replicated from the survey and 4 were the new findings in the representative sketching study.

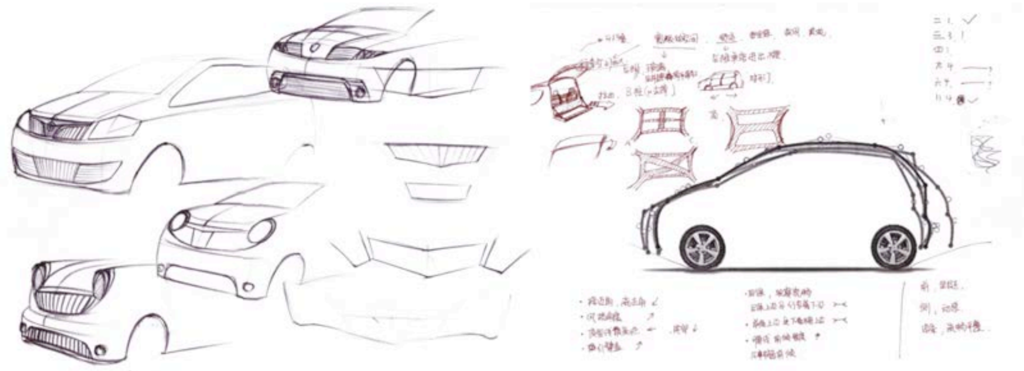

Figure 2. The Sketch from Tingting Hu in Styling Brand Elements Research

The survey and sketching study totally identified 19 styling brand elements and their shape grammars represented by feature lines. All the styling brand elements and shape grammars can be in two categories: detailed elements and holistic elements. For example, Figure 3 showed one holistic element: the lateral contour feature line and its shape grammars, in which the arrow described the shape transforming trend and the colored points were the possible positions of these control points.

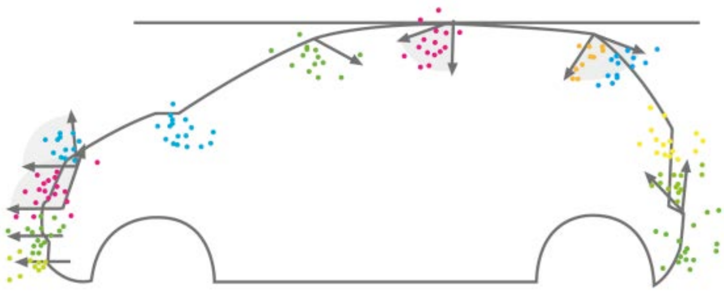

Figure 3. The Lateral Contour Feature Line (Holistic Element) and its Shape Grammars

3.2 Interactive Generative Design

The identified styling brand elements and their shape grammars provided the initial population of the generative design. Based on the identified brand elements, one hostile feature line – lateral contour feature line – was chosen to conduct interactive generative design. Figure 4 showed the controlled points of the lateral contour feature line.

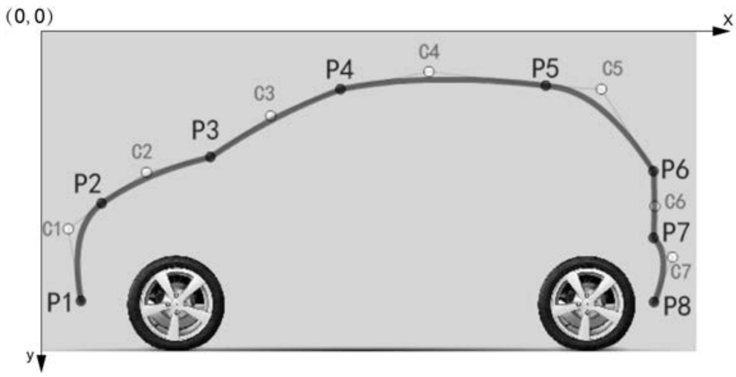

Figure 4. The Controlled Points of the Lateral Contour Feature Line

Based on Takagi's genetic algorithm theory [25], the interactive generative design of lateral contour feature lines consisted of four steps: coding initial population, setting up threshold, designing the operator, interactive generation and evaluation.

3.2.1 Coding feature lines

We defined the origin of spatial coordinates (0,0) based on the screen absolute coordinate, which is easy to reading data and operate genetic algorithm. Each 5 identified feature lines put into the coordinates as initial populations with the same position of front wheel center. The parameters of 15 points in Changan Benben micro-cars 5 lateral contour feature lines can be defined as Table 1.

Table 1. The Parameters of the Lateral Contour Feature Lines

Coordinates	C1	C2	C3	C4	C5
P1(x, y)	454.43,1748.72	439.83,1719.52	315.72,1807.11	454.43,1807.115	250.02,1719.51
C1(x, y)	293.831267.65	359.53,1274.95	323.02,1384.44	337.62,1464.74	213.52,1420.94
P2(x, y)	567.58,1091.72	567.58,1120.92	377.77,1201.21	479.97,1201.21	246.37,1237.71
C2(x, y)	844.98,935.86	844.98,928.56	823.07,950.46	808.47,965.06	742.77,986.96
P3(x, y)	1133.33,887.32	1242.83,836.22	1111.43,923.81	1096.82,916.51	1213.62,901.91
C3(x, y)	1542.13,654.45	1615.13,581.45	1578.62,617.94	1578.62,610.64	1666.22,617.94
P4(x, y)	1939.61,463.92	2049.11,420.12	1895.81,471.21	2202.41,507.71	2253.51,449.31
C4(x, y)	2589.31,332.15	2596.61,310.25	2567.41,324.85	2611.21,368.65	2647.71,354.05
P5(x, y)	3461.66,449.32	3322.96,398.58	3833.96,529.61	3563.86,566.11	3585.76,485.81
C5(x, y)	3687.96,505.53	3666.06,417.92	3724.46,549.32	3666.06,563.92	3921.56,636.92
P6(x, y)	3939.81,945.72	3990.91,919.80	3910.61,938.415	3830.31,1055.21	4158.81,931.11
C6(x, y)	3990.91,1128.95	3998.21,1136.24	3990.91,1143.54	3888.71,1136.24	4217.21,1099.74
P7(x, y)	3976.68,1310.72	3991.27,1332.61	4013.17,1376.41	3837.97,1230.41	4290.57,1281.51
C7(x, y)	4115.38,1441.02	4108.08,1448.32	4129.97,1462.92	4049.67,1411.82	4305.17,1426.42
P8(x, y)	3936.53,1734.12	3994.92,1726.81	4016.82,1668.41	3936.52,1734.11	4330.72,1697.61

On the basis of the parameters, the chromosome of the lateral contour feature line can be represented. For example, the lateral contour feature line C1 line can be represented as the following:

X_1= {454.43,1748.72, 293.831267.65, 567.58,1091.72, 844.98,935.86, 1133.33,887.32, 1542.13,654.45, 1939.61,463.92, 2589.31,332.15, 3461.66,449.32, 3687.96,505.53, 3939.81,945.72, 3990.91,1128.95, 3976.68,1310.72, 4115.38,1441.02, 3936.53,1734.12}

Then, all the chromosomes were transfer to binary codes in the following stages. Considered the understanding of the paper, we describe the following parameters and rules with chromosome representation.

3.2.2 Setting up threshold

Based on the vehicle styling and brand shape grammar in the styling brand elements research, we set up the control points threshold rules to ensure the generation results' validity. The rules consisted two types: the first is to ensure the generating feature lines accord with the micro-car's classification and the second is to ensure to keep the Changan Benben brand identity. There were 104 rules and thresholds in the study. For example, from the research we found that the deck lid of micro-car is higher than the hood about 150 mm, therefore, one of the micro-car's classification thresholds of controlled point P_7 can be defined as following:

When n=7,

$P'_{nx} < P_n + 1'_x$

$P'_{ny} < P_n + 1'_y - 150$

For another example of keeping the Changan Benben brand identity, angle between the lateral front bumper line and the horizontal line of Changan Benben is greater than 73 degrees, while other micro-cars of different brand is less than 70 degrees. Therefore, the thresholds of controlled point P_2 can be defined as following:

When n=2,

$$\arctan\left[\left(P_{1y} - P_{2y}\right) / \left(P_{1x} - P_{2x}\right)\right] \leq 73$$

3.2.3 Designing operator

Operator in generative design includes the value of crossover and recombination, the halting criteria, and so on [b]. The key issue of setting up the operator is the balance between the new styling generating and the brand identity reserving, which there were no existing experience to support. Therefore, we set up the initial operator from our experiences and insights and modified them systematically in generative design process. When one generation finished, designers evaluated the generated results and proposed the advices to modify the operator values.

In routine crossover and recombination, the value range of crossover probability (P_c) is from 0.25 to 0.75, while the value range of recombination probability (P_m) is from 0.01 to 0.2. Considered the limited generation individual number (only 5) and improving the innovation in styling generation, we defined the initial value of crossover and recombination as following:

P_m=0.28

P_c=0.45

In addition, we used the value of fitness as the halting criteria of generation. We defined the following as the halting criteria: the generation halted when there are 3 feature lines with fitness value reaching 4.

After five generations, we got the final operator values:

P'_m=0.3

P'_c=0.55

The halting criteria kept unchanging.

3.2.4 Interactive generation and evaluation

On the basis of thresholds and operators, we conducted the interactive generation and evaluation. The process of one generation is shown in Figure 5.

In the interactive generation, the initial population was generated based on the coded 5 populations. After the initial populations generated, designers were involved in the stages of evaluating the fitness of each individual and selecting the parents of next generation. Meanwhile, there were a self-learning mechanics based on artificial neural nets to acquire the knowledge and experience from human experts. By the mechanics, the algorithm can be improved and become to self-adaption evaluation and selecting process gradually. After the evaluating, if there is not satisfied with the halting criteria, the styling brand elements generate offspring from the 2 parents using crossover and mutation to form the next generation. In crossover, some parts of the chromosome of the two lateral contour feature lines were exchange and produced new feature lines. For example, the following X'_1 is the result of the crossover between C1 and C2. The underline parameters were the exchanged from C2.

X'$_1$= {454.43,1748.72, 293.83,1267.65, 567.58,1091.72, 844.98,935.86, 1133.33,887.32, 1615.13,581.45, 2049.11,420.12, 2596.61,310.25, 3322.96,398.58, 3666.06,417.92, 3990.91,919.80, 3998.21,1136.24, 3991.27,1332.61, 4108.08,1448.32, 3994.92,1726.81}

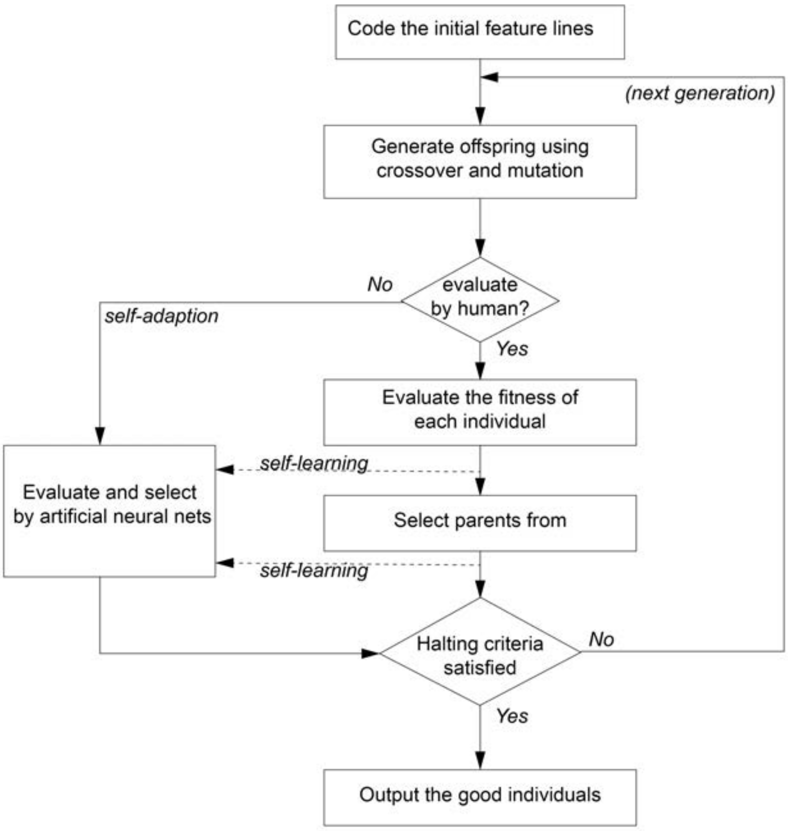

Figure 5. The process of one generation

In mutation, some of the parameters were changed by a systematic means. For example, the following X"$_1$ is the results of the mutation. The underline parameters were the changing chromosomes of C1.

X"$_1$= {454.43, 1748.72, 293.83, 1267.65, 567.58, 1091.72, 1021.57, 935.86, 1133.33, 887.32, 1542.13, 654.45, 1939.61, 411.13,2589.31, 332.15, 3461.66, 449.32, 3687.96, 505.53, 3939.81, 945.71, 3990.91, 1128.94, 3976.68, 1310.72, 4115.38, 1441.02, 3936.53, 1734.12}

If the halting criteria are satisfied, the generation finished and the good solution will be selected.

4. Results and the Application Design Case

In the design case of Changan Benben, the generative design iteration halted in the 12th generation with 44 new feature lines (Figure 6) while there are 3 individuals' fitness value reached 4.

From the all 12 generations' individuals, eight feature lines(Figure 7) based on the professional designers evaluation were chosen to be as the good feature lines of the following next generation's Changan Benben micro-car styling design, which were the key part of the product definition files. Based on the feature lines, designers build up the digital models (Figure 8) and finished three design proposals, and one of the three proposals entered the final list of the new styling R&D of Changan Benben, which initially proved the value and success of the research approach in practice. Figure 9 showed the expression and the photo of 1:10 model designing based on the generated feature lines.

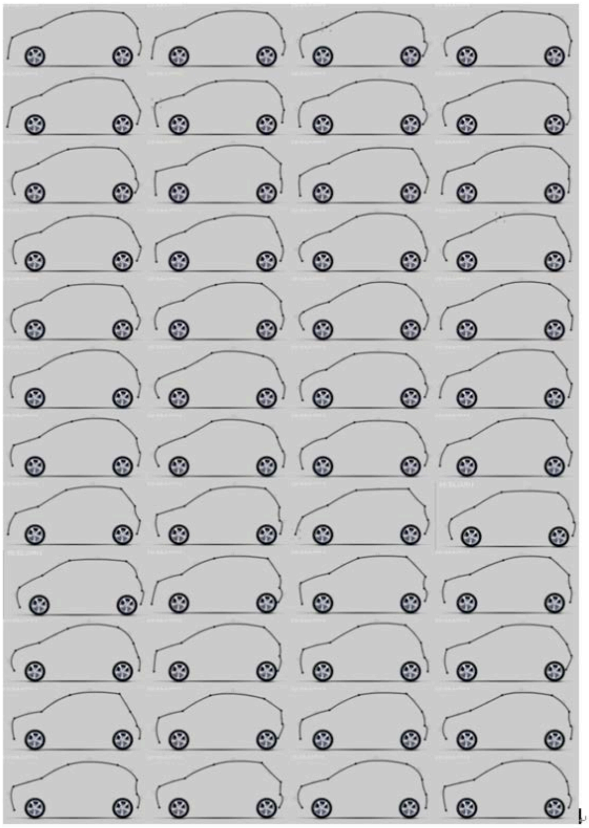

Figure 6. The Generated 48 Feature Lines

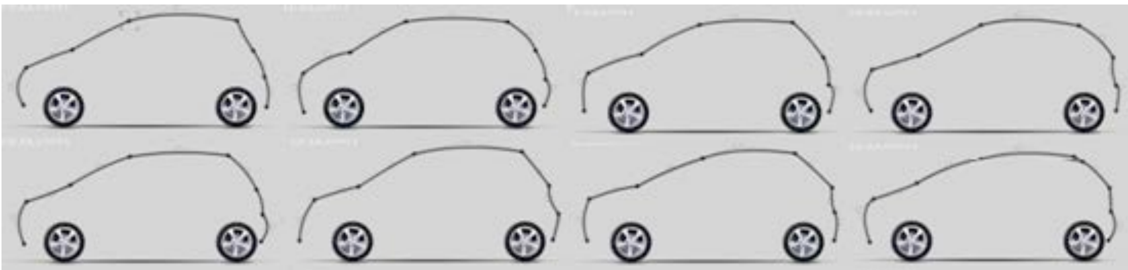

Figure 7. The Eight “Good” Feature Lines

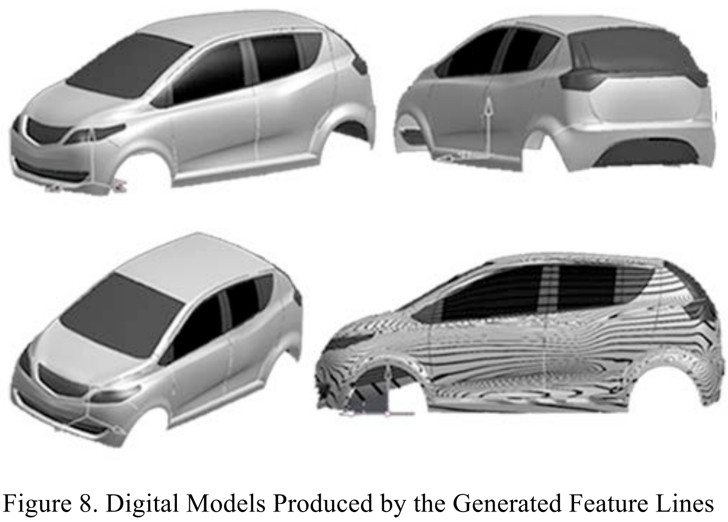

Figure 8. Digital Models Produced by the Generated Feature Lines

Figure 9. The expression and 1:10 model of new Changan Benben designing based on the feature lines (Designer: Tingting Hu)

5. Discussion

5.1 Genetic Algorithm as a Method of Designing Brand without Long Product History

In the study, we proposed a method using interactive genetic algorithm to conduct generative design to help such vehicles manufactures without long product history to design their brands from styling and gained the initial success. In fact, in brand design practices, there were many other approaches to build up a brand without good brand history, such as the Peter Schreyer's practices in KIA [12]. Generative design is one possible approach for the application practice seems to initially prove it. Nevertheless, in many designers' opinions, there is great risk to use a computer or artificial intelligence to conduct design approaches, for design is such a complex problem solving that it is hard to finish by some algorithm or mathematics methods. Designers' insights and experiences are very hard to be replaced by computers, especially in the styling and brand design. Therefore, the final purpose of the study is to use generative design method to help the design process instead of taking over it. In fact, in our study, designers also played a very key role in the generative design process that the generated results' evaluation was conducted by professional designers, instead of by computers. Though the self-learning mechanic were added in the algorithm, absolute self-adaption by algorithm itself is still very difficult when they face such complex design problems. In addition, the designers' intervention in the interactive evaluation may cause designers' personal factors (such as preferences) into the generation process. The result of the generative design is a region with series of solutions instead of many discrete solutions, which is very accord with the design practices. Therefore, the integration of designer and algorithm is the key issues in such studies instead of replacing each other. Obviously, the mechanism between human intelligence and computer intelligence in designing process is an important research question in the future studies.

5.2 The Balance between New Styling Generating and the Brand Identity Reserving

To most of the genetic algorithm and generative design, the generation means to explore larger design space and gains breakthrough styling. Nevertheless, the purpose of designing brand also includes the reserving of the brand identity. Therefore, the balance between innovating and reserving is a key issue in the study. On the one hand, the fitness value of halting generation is defined as 4. The fitness value in the generative design is from 0 to 5, in which 0 means unfitness (innovation) and 5 means absolute fitness (reserving). By the beginning five generations' trials, the value 4 exactly is a good balance between innovation and reserving. In fact, as classical opinions of Simon, the purpose of design is to achieve the satisfied solution instead of the most fitted solution[21]. On the other hand, in order to get the satisfied solutions, designers' subjective evaluation is a part of the evaluation and selecting the parents' samples in next generation. The intervention of professional experts can benefit for the balance of generation through their insight and experiences, especially in the initial stages to decrease the bias of the generation.

5.3 Lateral Contour Line as the Object of Generative Design

In the study, we chose one feature line the lateral contour line as the object of the generation. To choose the line as the object of generation is that considered the limited research schedule in the R&D process, Changan Benben's product director and chief designer's made decision to choose the line because they feel a hostile feature line may generate a hostile styling, which represents more than the detailed feature lines. As a case study, it is reasonable. However, there are many other key styling brand elements from the styling brand elements research. From large number of practices and experiences of brand design in vehicle styling [10,14,16], the detailed elements in front view often plays a key role in a vehicle's brand identity, such as grill, hood flow line, and so on. Therefore, in the future study, generative design in vehicle styling is to involve detailed identity elements and others in the generative design process. This suggests a challenge for the generative design: while there are two or more feature lines, the relationship in different feature lines are needed to be represented and as the generative objects according to the shape grammar. How to generate a relationship is obviously a new research question in the following studies.

6. Conclusions and Future Work

In the study we proposed a design research case by using interactive generative design methods to build up vehicle styling styling brand elements of Changan's micro-car Benben and applied the research results in the design practice to achieve the initial success, which was benefit to the fast-developing Chinese automobile industry and the R&D process.

In the next step, we will involve more feature lines as the objects of generative design and continue to study the shape grammar in the different feature lines. In the study, we should design a new method to describe and represent the relationship. Based on the representation and the research findings in the study, an experiment will be conducted to identify the elements of the brand in these relationships and the new genetic algorithm will be built up to generate new elements and their relationships.

In addition, we will try to transfer the method from micro-car to other vehicles, such as sedan, SUV, and so on, which would finally become a universal method in vehicle styling domain and will be benefit more in the developing vehicle industry in China.

7. Acknowledgments

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8. References

[1] Banzhaf, W., Nordin, P., Keller R. and Francone, F. (1998) *Genetic Programming - An Introduction*, Morgan Kaufmann, San Francisco, CA.

[2] Benoit, K. and Wiesehomeier N. (2009) *Expert Judgments*, in Pickel, S. (eds), Methods of Comparative Political and Social Science, pp 497-516.

[3] Bies, R., Muldoon, M., Pollock, B., et al. (2006) *A Genetic Algorithm-Based, Hybrid Machine Learning Approach to Model Selection*. Journal of Pharmacokinetics and Pharmacodynamics (Netherlands: Springer), pp 196–221.

[4] Cagan, J. and Vogel, C. (2002) *Creating breakthrough products: innovation from product planning to program approval*, Financial Times Prentice Hall, Upper Saddle River, NJ.

[5] Cheng, J-C. and Ho, M-C. (2012) *The Shaping and Expression of Product Happiness Imagery*. In Proceedings of DRS 2012, Faculty of Architecture, Chulalongkorn University, Bangkok, pp 260-272.

[6] Ding, L., & Gero, J. S. (2001) *The emergence of the representation of style in design*. Environment and Planning B: Planning and Design, vol. 28, no. 2, pp 707-731.

[7] Dorin, A. (2001). Aesthetic Fitness and Artificial Evolution for the Selection of Imagery from the Mythical Infinite Library. In Kelemen, J. & P. Sosík (eds), Advances in Artificial Life, Proceedings of the 6th European Conference on Artificial Life, vol. LNAI2159, Springer-Verlag, Prague, 659-668.

[8] Forbes. *The most important car on earth: Can China's Changan Benben Save GM* . Available at <http://www.sgmw.com.cn/SGMW/templates/TE_news-SGMW/content.aspx?nodeid=181&page=ContentPage&contentid=1271> [Accessed 15 January 2013]

[9] Kapferer, J. N. (2012) *The New Strategic Brand Management: Advanced Insights and Strategic Thinking*, 5th Revised edition, Kogan Page Ltd, UK. [B] Karjalainen, T.-M., & Snelders, D. (2010). *Designing visual recognition for brand*, Journal of Product Innovation Management, vol. 27, pp 6-22.

[10] Karjalainen, T.-M. (2007) *It looks like a Toyota: educational approaches to designing for visual brand recognition*. International Journal of Design, vol. 1, pp 14.

[11] Karjalainen, T.-M., & Snelders, D. (2010). *Designing visual recognition for brand*, Journal of Product Innovation Management, vol. 27, pp 6-22.

[12] KIA Corporation. *Design Make Brand*. <http://www.kia.an/chief_design_officer.php>[Accessed 15 January 2013]

[13] Kosorukoff, A. (2001). *Human-based Genetic Algorithm*. IEEE Transactions on Systems, Man, and Cybernetics, SMC-2001, pp 3464-3469.

[14] Liem, A., Abidin, S., & Warell, A. (2009). *Designers' perceptions of typical characteristics of form treatment in automobile styling*. In 5th International Workshop on Design & Semantics of Form and Movement, DesForm 2009. Taipei.

[15] McCormack, J. P. and Cagan, J. (2002) *Designing inner hood panels through a shape grammar-based framework*, Artificial Intelligence in Engineering Design, Analysis and Manufacturing, vol. 16, no. 4, pp 273–290.

[16] McCormack, J. P., Cagan, J., and Vogel, C. M. (2004). *Speaking the Buick language: capturing, understanding, and exploring brand identity with shape grammars.* Design Studies, vol. 25, no. 1, pp 1-29.

[17] Oxman, R. (2006). *Theory and design in the first digital age*. Design Studies, vol. 27, no. 3, 229-265.

[18] Pugliese, M. and Cagan, J. (2001) *Capturing a rebel: modeling the Harley–Davidson brand through a motorcycle shape grammar*, Research in Engineering Design, vol. 13, pp 139–156.

[19] Ranscombe, C., Hicks B. and Mullineux, G. (2012) *A method for exploring similarities and visual references to brand in the appearance of mature mass-market products*, Design Studies, vol 33, no. 5, pp 496-520.

[20] Ranscombe, C., Hicks, B., Mullineux G., et al. (2012)*Visually decomposing vehicle images: Exploring the influence of different aesthetic features on consumer perception of brand*, Design Studies, vol. 33, no. 4, pp 319-341.

[21] Simon, H. A. (1996) The Sciences of the Artificial, 3rd Revised edition, MIT Press, US. [O] Soddu, C. (1999). *Generative Art*, Editrice Dedalo Publisher, Roma.

[22] Singh, V. and Gu N. (2012) *Towards an integrated generative design framework*, Design Studies, vol. 33, no. 2, pp 185-207

[23] Stiny, G. and Gips, J. (1972) *Shape Grammars and the Generative Specification of Painting and Sculpture*, in Freiman, C. V. (ed.) Information Processing 71, IFIP, North-Holland Amsterdam , pp 1460–1465.

[24] Soddu, C. (1999). *Generative Art*, Editrice Dedalo Publisher, Roma.

[25] Takagi, H. (2001) *Interactive evolutionary computation: fusion of the capabilities of EC optimization*. Proceedings of the IEEE, pp 1275-1296.

[16] Tan, H., Zhao J. H., Tan, Z. Y., et al. (2009) *Build the Emotional Genetic Model to Generate New Automobile Form in Concept Design*, In Proceedings of IEA 2009, Beiijing, China. [K] Vose, M. (1999) *The Simple Genetic Algorithm: Foundations and Theory*, MIT Press, Cambridge, MA.

[27] Vose, M. (1999) *The Simple Genetic Algorithm: Foundations and Theory*, MIT Press, Cambridge, MA.

[28] Wang, W. and Zhao, J.H. (2007) *Semantic Analysis of Automobile Modeling Based on Circumstances, Art and Design in China*, vol. 50, no. 2, pp 107-108. (in Chinese)

[29] Warell, A. (2004). *Towards a theory-based method for evaluation of visual form syntactics*. In H. Xirouchakis (Ed.), TMCE, tools and methods for competitive engineering. Lausanne: Mill Press.

[30] Zhao, D. H., Zhao, J. H. and Tan, H. (2009) *A Feature-Line-Based Descriptive Model of Automobile Styling and Application in Auto-design*. In Proceedings of IASDR 2009, Souel, Korea.