# Application of an Interactive Genetic Algorithm in the Conceptual Design of Car Console

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*Abstract:* - Interactive genetic algorithms are effective methods applied into the conceptual design of car console in order to better cater to the customer's individualized demands for product design. In traditional interactive genetic algorithms, users' fatigue problem restricts the population size. We propose individual fitness estimation method based on artificial neural network to reduce user fatigue problem and maintain large population size, as well as hierarchical interactive genetic algorithm to make the evolution of the population more directional and the combination of collaborative interactive genetic algorithm based on users' preferences to implement the user personalized design system for car console. Through the establishment of the car console conceptual design system, the users interact with the system by a graphical interface. Results prove that they could conveniently design their favourite console, and their fatigue problem can be effectively solved by this system.

*Key-Words:* - Car console; conceptual design; interactive genetic algorithm; artificial neural network; user fatigue

## 1 Introduction

The complicated product market in the 21st century requires that product manufacturing enterprises are able to quickly supply the most types of customized products in the whole word. Therefore, the customer-oriented design, responding quickly to customers' demand, will be intensively concerned by most companies in the highly competitive market [1-5].

Applying the product modularization to design, manufacture and configuration is a kind of strategy to solve the problem of quickly responding to customers' demand. According to customers' demand, the final products are manufactured or assembled after the product model is designed, manufactured or bought in advance. As to some more complicated products, their large amount of alternative model leads to assemble explosion. In spite of various constraint factors, a feasible product configuration solution with large amount could be found out. However, the individuality and variety of customers' demand develop deeper and deeper; it is hard for customers to find out their satisfactory products. And it is also difficult for the traditional product configuration process to satisfy customers.

Additionally, with the development of social economy, the dominant market of satisfying customers' demand is gradually developed. When the customers encounter a concrete product, they will be impressed by the product appearance with their special feeling, which is the customers' common psychological reaction to the product sign [6]. Hence, it is a new trend that the customers' affection will be fused into the operating process of designing product appearance, which is called as "Form follows Affection" [7]. Now many researches could facilitate to explain the relationship between affective reaction and product appearance [1, 3, 6, 8-11]; however, there are few researches to discuss about how designers combine the customers' affective reaction with design creation or process system.

We may try that according to the customers-participating designing project, manufacturing enterprises customize the product to satisfy their individualized demands, and it could be a perfect solution. As most customers are not professional in design, the designers usually need to change the customers' demand into design solutions. However, the solution is time-consuming and cost-consuming. If the customers can directly self-design in line with their demand, or participate in the designers' work, the efficiency would be much improved. While precise computer aided design system will contribute to help the customer to choose and customize their favorite design, it is necessary to specialize on it. The paper aims at helping customers to efficiently choose out their favorite design by establishing computer aided design system for layman.

In the paper, a product design auxiliary system is developed by using Interactive Genetic Algorithm with the example of the conceptual design of family car console. As we all known, the research on IGA used in car configuration design is few. So, in the paper, the car console configuration design is taken for instance to verify IGA could be efficiently and suitably applied into car industry, which supplies competitive product configuration solution for cars and other complex product enterprises. The console of family cars is divided into several mutually constraint models which are established as separate 3D model by OpenGL and GLUT, and then the individual design is generated from the composition of these models. By interacting with the users, the system could effectively figure out the most alike to customers' favorite designs.

The paper structurally develops as the following: the second part focuses on the relevant background knowledge; the third part sketches out the system and design; the fourth specializes on the system implementation; in the final part, the results are discussed and the conclusion is reached then.

## 2 Literature Review

### 2.1 Subsection the Conceptual Design of Car Console

The conceptual design is the key activity in the early stage of product design, and it involves the generation and evaluation of product concept etc [12]. Generally, the conceptual design includes the demand analysis of product and the outline design: function design, principle of design, shape design, layout design and preliminary structure design etc [13]. By considering many constraints and design goals, product conceptual design is finally developed into product design scheme by generating and selecting concept. Especially for design of the complex product, the designers often encounter difficulty in optimized several objectives in the given feasible area. Designing of a new product, for instance, the usability, manufacturing cost and the manufacturability, reliability and maintainability of product etc. are all needed to be considered. The improvement of these design objectives may contradict each other, so the compromise and balance among them must be reached. The optimization of several objectives in given area is called multi-objective optimization. Usually, the solutions to the problem are with large space dimensionality, and there are so numerous schemes after combination that it is difficult to evaluate the schemes one by one and obtain the optimal solution.

At any time, car drivers and front row crew need to contact with instrument panel, so the design and layout of console influence the car's comfort and the driver's feeling. That is to say, the console, to some extent, mirrors the comfort and function of a car, and it is an important reference to measure the performance of a car. The design of car console covers three shape elements: outline, detail and decoration. The outline is the sketch or the appearance showing the whole feature of console; the detail element consists of instrumental panel, steering wheel, SZM and air condition outlet etc, which are all from the above outline; the decoration means all the elaborate adoring. In the paper, we mainly focused on the detailed element, and the common details are shown in Fig. 1.

Instrumental Panel: it is used to display the working condition of every function of cars and mainly includes display device of speed, engine speed, water tank temperature and fuel amount etc. The traditional instrumental panels are mechanical, while now they are replaced by electronic ones.

SZM: it is in the central of the inner which reveals its importance to car. There are the buttons of air-condition, sound and other comfort and entertainment devices on the SZM.

Steering wheel: it orientates the direction and controls the turning.

Gear shift lever: it could change speed by changing the position of the gear engagement in transmission.

Air-condition outlet: it is ventilation opening of cars' air-condition.

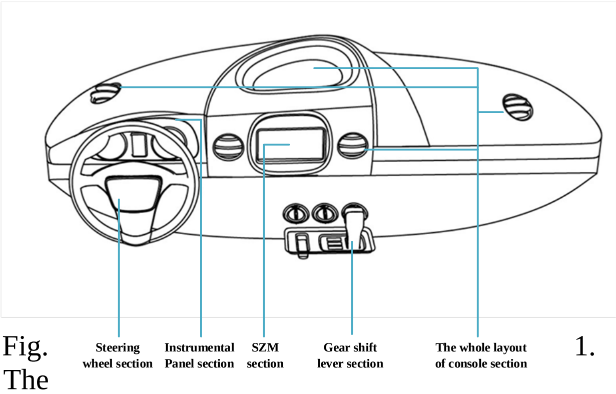



Fig. 1. The Common Details of Car Console

## 2.2 Computer Aided System of the Car Conceptual Design

Developed in the late of 1950 in last century, Computer-aided Design (CAD) and Computer-aided Manufacture (CAM) bring about qualitative leap in the designing approach for cars. Now, they become important tools to develop new product, organize mass production and enhance competitiveness. And the techniques play decisive roles in shortening the product development circle, improving product performance and lowering product cost, which produce tremendous economical and social benefits to enterprises. For example, CAD/CAM is used into cars' design in GM Company (General Motor) in America, which shortens the design circle of a brand-new motorcycle type from 5 year to 36 months.

The traditional software technique of CAD is mainly applied into product modeling. While it could free people from heavy work, shorten production circle, ensure design accuracy, and lower the cost of design and development in application, the traditional CAD is only useful in finalizing the modeling, rather than designing modeling; therefore, the original CAD system only does a small portion of the whole design work because when designer are doing design work, they have already planned well the outline of the design, but they don't actually do the design work.

Nowadays the popular CAD software which supports innovative design is Auto CAD, Maya, CATIA, Pro/E, SolidWorks, CAXA etc. They mainly focus on easy operation (moving mouse) and collaborative design; however, the innovative design essentially originates from the designer's inspiration, unable to accurately locate the product users or customers' demands, let alone their individualized needs. Therefore, the paper aims to design a product design system which can take the customer' demands into thorough consideration; consequently the customers could create custom design themselves by using the product design system.

## 2.3 Interactive Genetic Algorithm

Genetic Algorithm (GA) was brought up by John Holland in 1970, and it applied several natural evolutionary mechanisms into optimization and machine learning, such as crossover, mutation and survival of the fittest. As GA only needs the valuing information of optimal objective rather than gradient information, it could be used into the nonlinear inconsecutive multimodal function. Now, GA is widely applied into many fields, such as function optimization, organization optimization, production dispatching, automatic control, robot intelligent control, image processing, pattern recognition, artificial life, programming and machine learning etc.

The traditional GA usually needs the explicit fitness of optimal objective; nevertheless, not all the fitness of optimal object could be explicitly displayed. It is difficult to show the fitness by the explicit function in product designing, costume designing and musical composition creation etc. because of human's subjective factors (experience, mentality, goal and so on). In allusion to the above problems, Interactive Genetic Algorithm (IGA) is put forward.

In IGA, the fitness of every individual is given by the users instead of computed by fitness function. In this way, IGA could not only interact with the users but also apperceive their mood or preference. Hence, IGA can be used to resolve the problems which GA fails such as artistic or industrial designing [14-17] and musical creation [18] etc.

The advantage of IGA instead of GA will be illustrated with examples. The goal of car console configuration design is to produce good sense of beauty in appearance on the basis of basic functional quality. By initialization, firstly to design the population of individuals which is characteristically encoded, and then to set up and evolve its fitness on the basis of "the excellence of the design", GA could also be used into the cars' inner console design. However there is no norm to measure the design because almost every customer has different feeling, and it is impossible to organize fitness function, even possible, and the function would be out of date and becomes invalid; whereas IGA could work out all the problems. IGA could reflect individual's preference or constantly changing popularity conditions as it gets fitness directly from the users rather than by function-computation.

### 2.4 IGA Based on Neural Network

Since being proposed in1940s, the artificial neural network has been widely used in the areas of pattern recognition, complex system optimization and control and magnanimous information processing etc. It is a new type of intelligent information processing system imitating the feature of human brain neuron, and the artificial neural network is characterized with excellent features of self-adaption, self-origination, fault-to-learn and so on. It's worth noting that it possesses very strong nonlinear mapping ability; hence the artificial neural network is an effective tool of curve fitting, approximate nonlinear complex system. Using these features, GA and neural network could be combined [19] to efficiently lower the users' fatigue in IGA.

Many scholars at home and abroad have done researches on its application. Reference [19] showed that the method of combining IGA and neural network is used to predict the short-term earthquake, and a new method has been put forward by using IGA to train weight of neural network; Ref. [20] proposed the evolutionary individual fitness based on neural network could be evaluated on different stages. Actually, the evaluation of evolutionary individual fitness based on neural network is divided into the sketchy evolutionary stage and precise evolutionary stage. In the former stage, as the individuals are discrete, they greatly differ in fitness; therefore the requirement of models' precision is not high, and their threshold value could be large. In the latter stage, the individuals tend to convergence, and it is hard for neural network to differentiate their fitness as there is little difference between them. Therefore, individual evaluation needs to be carried out by human, and the results of evaluation are treated as samples for neural network to continue learning [20]. More information about it is displayed in Refs. [21,22,23]. In this paper, the method of IGA by using artificial neural network is proposed and improved on the above methods.

### 2.5 Collaborative IGA on the Basis of Users' Preference

On the basis of users' preference, collaborative IGA is a kind of collaborative evolutionary genetic algorithm among many populations. It means more than one population is involved in evolution, and these populations cooperate with each other and exchange evolutionary information in their evolutionary process. In other words, it is not only the relationship between population and environment but also the relationship among populations that are taken into consideration to carry out optimization by the collaborative evolutionary genetic algorithm in many populations. The collaborative of evolutionary genetic algorithm in many populations is devised on the foundation of pure evolutionary genetic algorithm in many populations [24]. As we all known, different users might have a similar preference; hence the extract and saving of similar users, as well as the search of similar users' preference [25], are the key of the collaborative of evolutionary genetic algorithm in many populations [20].

The individual preference similarity between users $u_1$, $u_2$ could be calculated in function (1):

$$\begin{cases} \delta = \frac{1}{n}\sum_{i=1}^{n}\sigma_i(u_1,u_2) \\ \varepsilon = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\sigma_i(u_1,u_2)-\delta)^2} \end{cases} \quad (1)$$

In which, $\sigma_i(u_1, u_2)$ is the $u_1$, $u_2$ users' similarity of preference to component Ui, and it could be computed in the function [2]:

$$\sigma_i(u_1, u_2) = \frac{1}{|U_i|}\sqrt{\sum_{j_p=1}^{|U_i|}(F_{u_1}(U_i^{j_p}) - F_{u_2}(U_i^{j_p}))^2} \quad (2)$$

In which, $U_i^{j_p}$ denotes allele meaning unit of the constituent factor $U_i$ ; $F_{u_1}(U_i^{j_p})$ and $F_{u_2}(U_i^{j_p})$ respectively denotes $u_1$, $u_2$ users' preference to allele meaning unit of the constituent factor $U_i$; $U_i$ means the No. of the allele meaning unit of the constituent factor $U_i$.

Hence, from the above function, it can be seen that the smaller δ is and the smaller ε is, the higher the similarity between $u_1$, $u_2$ users' preference to all gene units is, and the higher the similarity between $u_1$, $u_2$ users' preference to certain gene units of evolutionary individuals is. Otherwise, when the larger δ is and the larger ε is, the higher the discrepancy of similarity between $u_1$, $u_2$ users' preference to all gene units is, and the higher the discrepancy of similarity between $u_1$, $u_2$ users' preference to certain gene units of evolutionary individuals.

## 3 System Design

The flowchart of system design is shown in Fig. 2. It can be seen that various design model are stored in specific elements database. At first, the system selects the models of every part and combines the models to some individual designs. The population evolutionary individual is displayed in users' interface in the graphic form, and their fitness is given by the users. And then in view of the fitness of every evolutionary individual, their population are duplicated, mutually crossed, mutated and generated the next generation by the system; the results are still displayed in users' interface in the graphic form. At the same time, artificial neural network continues to learn the users' knowledge till the learning precision meets the requirement, and then it replaces the users to evaluate evolutionary individual and generate the next generation by crossover and mutation. The above process iterates to generate the population with much higher fitness. Nevertheless, once the populations are evolved to certain stage, the difference in the individuals' fitness will be less and less, and it will be not effective to search at this stage. Then, the populations are evolved into local search stage. The users appoint the searching area, and the evolutionary individual will be generated the next generation by crossover and mutation. In the meanwhile, according to local search area selected by users, the system searches for the most optical individual of users' similar preference. The two types of individuals are both displayed in users' interface in the graphic form to generate population with higher fitness and better design.

### 3.1 Interacting with Users by GUI

Users could achieve man-machine interaction by graphical interfaces. Before man-machine interaction, the individual (console) has been separated into several modules (every module stands for a gene unit) and encoded. Before evaluating, users can weight each gene unit, in other words, users attach different importance to different gene units. Just like the case in the paper, users might regard steering wheel and instrument panel more important, so their weights are defined as 0.2, and the rest are 0.15. For the sake of easy computation, mean weights are set up in the paper with no influence on the system efficiency. After decoded, the individuals are showed by graphical interface in 2D form; additionally, the 3D pictorial button is also equipped for users. If the users are interested in some individual, they could have 3D picture by pressing the 3D button. Users need to evaluate every picture before artificial neural network finishes learning about the users' demands; once it has grasped the user' demands, they could choose artificial neural network to facilitate assess. After users' evaluation or neural network's evaluation, new pictures of a new generation will be displayed in the graphic interface. And once the users have evaluated these pictures, the neural network will automatically learn how to modify the forecast of the system with its new evaluation, further it will improve assessed value, speed up convergence and provide data for system to learn. In each step, the graphical interface is applied by the system to evolve individuals. By iterating the above process, the evolutionary individual with higher fitness could be generated, i.e. better design is realized; users' satisfactory picture will be obtained by repeating the process.

### 3.2 Flow and Steps of the Algorithm

According to the designed system structure, the author devises the following algorithm flow and step in Fig. 3.

Arithmetic steps:

Step 1: to set arithmetic controls parameter;

Step 2: to generate initialized population;

Step 3: to decode and show to users in graphic form; user evaluates evolutionary population;

Step 4: whether the users are satisfied or not, if they are, to output the optimal solution, and the algorithm ends; if not, turn to step 5;

Step 5: the system inquires the users whether they continue to evaluate individuals; if they are, turn to step 6, and if not turn to step 7;

Step 6: to carry out genetic manipulation, generate a new generation population, turn to step 3;

Step 7: the system uses artificial neural network to evaluate evolutionary individual in stages, and uses hierarchical IGA to search locally; genetic manipulation is carried out in inner system to generate a new generation population; the system defines the individuals' fitness;

Step 8: to submit the optimal individual of the evolutionary population;

Step 9: whether the users need co-evolution or not? If they do, according to the above (2), choose out users with the similar preference, and turn to step 10; if not, turn to step 11;

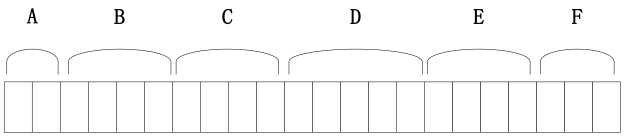
Step 10: to visit the optimal individuals of evolutionary population where the users with the similar preference are.

Step 11: whether the current users are satisfied with the individual or not; if they are, the algorithm ends, and if not, users evaluate the individual, and turn to step 6.

# 4 System Application

## 4.1 System Application

On the basis of the above description about the system, it is necessary to clearly understand every element of the evolutionary individuals. Therefore, the paper introduces gene unit and allele unit, and encodes detail model. At first, the common detail factors in Fig. 1 are re-divided into five sections shown in Fig. 4, and they are the whole composition of console, steering wheel, instrument panel, SZM and gear shift lever. And then, the five parts are encoded, in which three bits are added for whole color style to choose. Every part and the color style consist of a design. The users' favorite design combination could be figured out by using IGA, and more rational design will be generated. The details of encoding will be illustrated as follows. Given the limited space, only steeling wheel and SZM taking for instance in the paper.




A: Console Whole Composition Section
B: Steering Wheel Section
C: Instrument Panel Section
D: SZM Section
E: Gear Shift Lever Section
F: Color Style Section

Fig. 4. Encoding Module

- Console whole composition section: including the framework design of console and air outlet; totally four models; encoded by 2 bits.
- Steering wheel section: as shown in 4-3, including steering wheel, horn button, steering lamp, headlight button, as well as the trigger buttons of headlight, wiper and other function keys button; totally four models; encoded by 4 bits.
- Instrumental panel section: including tachometer, speedometer, and some display screens of the other status of cars; totally sixteen models; encoded by 4 bits.
- SZM section: as shown in 4-4 covering navigator, music player, the adjust button of air-condition, car telephone, the button of caution light for danger and other function keys; totally twenty-six models besides wireless navigator and car telephone; encoded by 5 bits.
- Gear shift lever section: including shift level of transmission, parking brake, ashtray, cigarette lighter and other function keys; totally nine models; encoded by 4 bits.

Thereby, it is necessary to add three bits to complete chromosome coding so that the users could choose their favorite color in the 8 selective color styles. A wholly encoding chromosome is shown in figure in 4-6. By computing all the combinations of the designs and its corresponding color, the size of search room is worked out as 1,437,696 ($4\times12\times16\times26\times9\times8=1,437,696$), from which the optimal design will be searched out according to the users' preference and mood feedback.

## 4.2 Users' Interface

In order to ease the interaction between the users and the system, it is essential for the system to display 3D graphics for users. At first, a 3D model for each component element of the design should be established, and Fig. 5 has shown an example of 3D model for steering wheel to reveal the 3D model; then the combined 3D model will consequently be shown by the system on the basis of decoding of individual gene type. The current evolutionary individual is displayed in the screen by the system, just like what are demonstrated in Fig. 6. Below the design of every evolutionary individual, a slider is used to achieve users' feedback or preference. Besides, the current evolutionary individuals' status is revealed in the users' interface: the optional individual in the last generation and the current optional individual, so are the control buttons of "into next generation" and "use ANN to evaluate", as well as other information for users to operate in the interface. Hence, by interacting with the system, the users could find out their favorite design in the larger searching room.

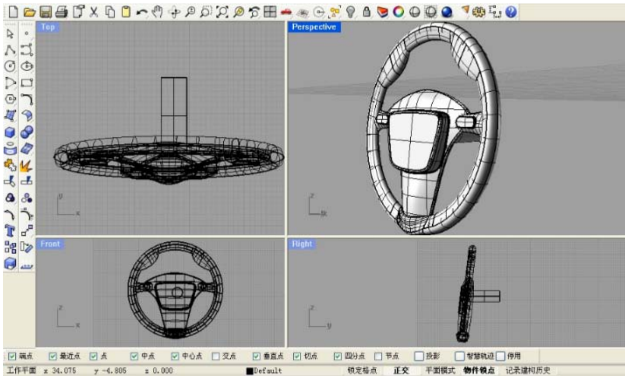


Fig. 5. Constructive Process of 3D Model of Steeling Whale

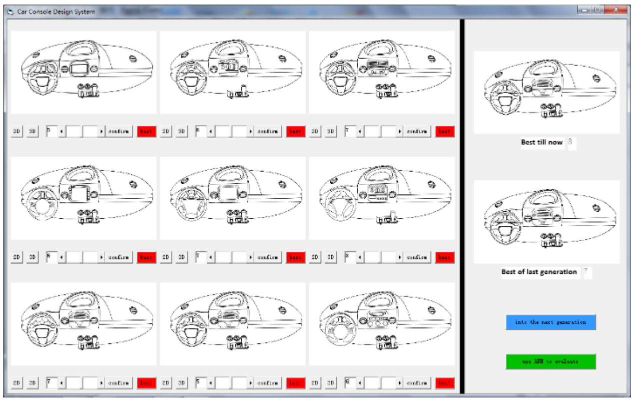



Fig. 6. Main Interface of Interaction

### 4.3 Performance Analysis

As IGA design system is used to reduce the frequency for human to evaluate the evolutionary individual, so as to lighten their fatigue, and its usage to lower users' fatigue is analyzed here to testify its effect.

In the paper, N is deemed as the range of evolutionary population; T as the number of ending evolutionary generation, $T_1$ as the number of evolutionary generation before the environment is stable, T – $T_1$ as the number of evolutionary generation after the environment is stable. In the traditional IGA, NT is set as the number of evolutionary individuals evaluated by users before their evolution ends.

At first, IGA based on artificial neural network is discussed. In the two stages the number of sample needing learning is set as $2N_1$; the number of sample needing testing the learning effect of neural network as 2Nt; both of which could be obtained by the users evaluating evolutionary individuals, in other words, the number of evolutionary individuals evaluated by users is deemed as $2(N_1+N_t)$. In the evolutionary process, the total amount of evolutionary individuals evaluated by users is $NT_1 + 2(N_1+N_t)$, thereby, the fact that some evolutionary individuals are evaluated by neural network makes the number of evolutionary individuals not evaluated by human as $NT - (NT_1 + 2(N_1 + N_t))$, i.e. $N (T - T_1) – 2(N_1 + N_t)$. It is observed that regarding IGA based on artificial neural network, the key effect of artificial learning is to lower users' fatigue. In the next part, the degree for hierarchical IGA to ease users' fatigue is analyzed. As IGA in the whole searching stage has the same efficiency when directly used, only its efficiency in local searching stage is specialized on in the paper.

In local searching area, the maximum of individual with allele unit is $K_{lj}$. Actually, the optimal individual is reserved, and the worst individual is replaced in the evolutionary process. As hierarchical IGA is a kind of search based on population, it surely could seek out the optimal solution after $K_{lj}$ –(N – 1) iteration at most; While by using IGA directly, it usually needs $K_{lj}$ iteration to certainly work out the optimal solution in local searching area with $K_{lj}$ allele unit.

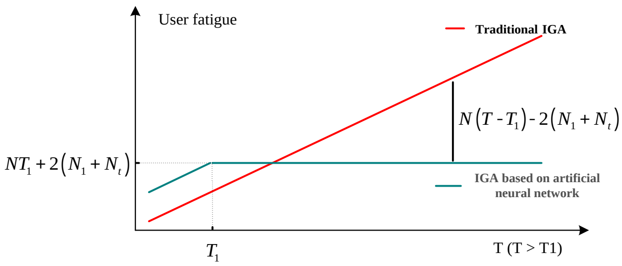



Fig. 7. Users' Fatigue Analysis

It can be easily seen from Fig. 7 that when the evolutionary generation number T increases, the evolutionary generation number evaluated by human$NT_1$ + $2(N_1+N_t)$ still remains the same; therefore, the users' fatigue doesn't increase. It usually goes N > 1, so $K_{lj}$ - (N – 1) < $K_{lj}$ could be speculated, which means the arithmetic could increase the evolutionary generation number without increase users' fatigue. Once combined with hierarchical IGA, IGA based on artificial neural network could greatly enhance the number of evolutionary generation to offer the better evolutionary individual in wholly searching stage; in the local searching stage, as it is easy to discriminate the difference in the individual, it could provide more accurate fitness to improve its precision. As a result, to integrate two kinds of arithmetic could not only guarantee the enough evolution generation but also make the users gain their satisfactory product design in the possibly short time. In addition, nowadays the internet technology develops at high speed; if collaborative IGA is used to search the users with similar preference to provide product reference, the convergence of population will be further speeded up, and the diversity of product will be enriched.

## 5 Conclusion

In order to lighten the users fatigue in IGA, the method of evaluating individual fitness based on artificial neural network, as well as the method of combination of hierarchical IGA orientating population evolution and collaborative IGA based on user preference, is brought forward in the paper to realize the users' design system of car console. All based on the disintegration of the evolutionary individual gene unit of sense, the above methods use individual information to evaluate the allele unit of sense fitness of every gene unit of sense, further the allele unit of sense fitness to evaluate individual fitness, and then the gene unit of sense to spread the whole individuals' fitness for users to evaluate. In this way, they could better orientate population evolution to reduce evolution generation number and save the system's resources; as a matter of fact, the essence of the methods is to extract and apply the knowledge in the evolutionary process. The arithmetic works on the premise that the individual gene type is disintegrated into gene units of sense, so their usage is confined; however, in most situation, there is no adversary influence on their use just like the design of car console in the paper; the individual gene type could be divided to 5 gene units of sense: console whole composition, steering wheel instrument panel, SZM, gear shift lever and color style. Additionally, the users could weight every gene units of sense consisting of individual, which makes the evolutionary individual better to satisfy the users' preference. In consequence, much more satisfactory products are designed for users. To sum up, this method relieves users' fatigue, and it is more appropriate to satisfy the users' demand by interacting with them and can be researched further widely.

Meanwhile, the design system with users' participation put forward in the paper meets their individualized demand. It integrates customers' affection into the operation process of car console layout design so that their really satisfactory product is customized, and it provides a new method for many manufacturers to quickly and accurately gain customers' preference and requirement which makes them more competitive in the market. The design system efficiently breaks the ice that it is hard to surmise customers' preference and the product is too monotonous in car industry. Further, it opens up new direction for future development in car industry. With wide application prospect, the method is also suitable to other manufacturing industries, such as clothes, furniture and etc. In near future, it is believed that the customers could customize their favorite product design for food, clothing, shelter and transportation from product design manufacturing enterprises which manufacture their product according to their customized product design.

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# Appendixes

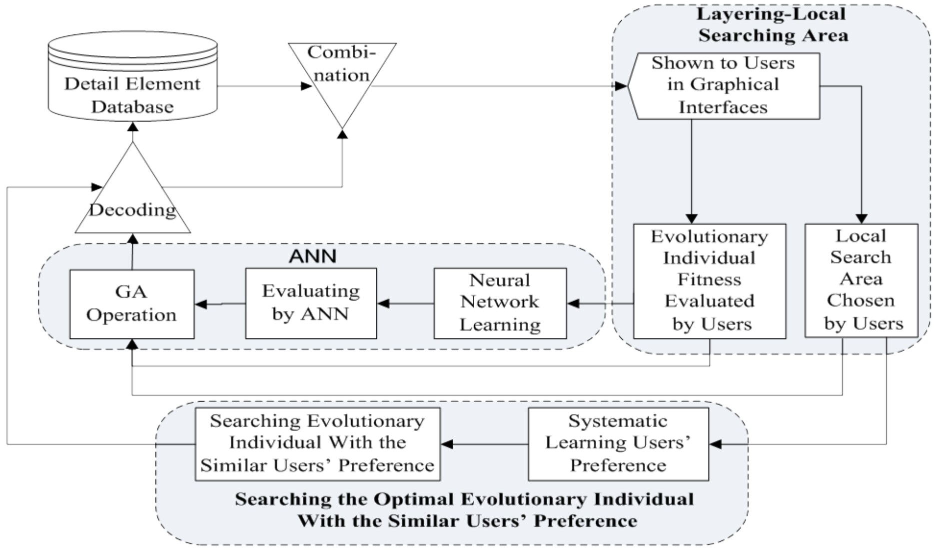


Fig. 2. System Flowchart

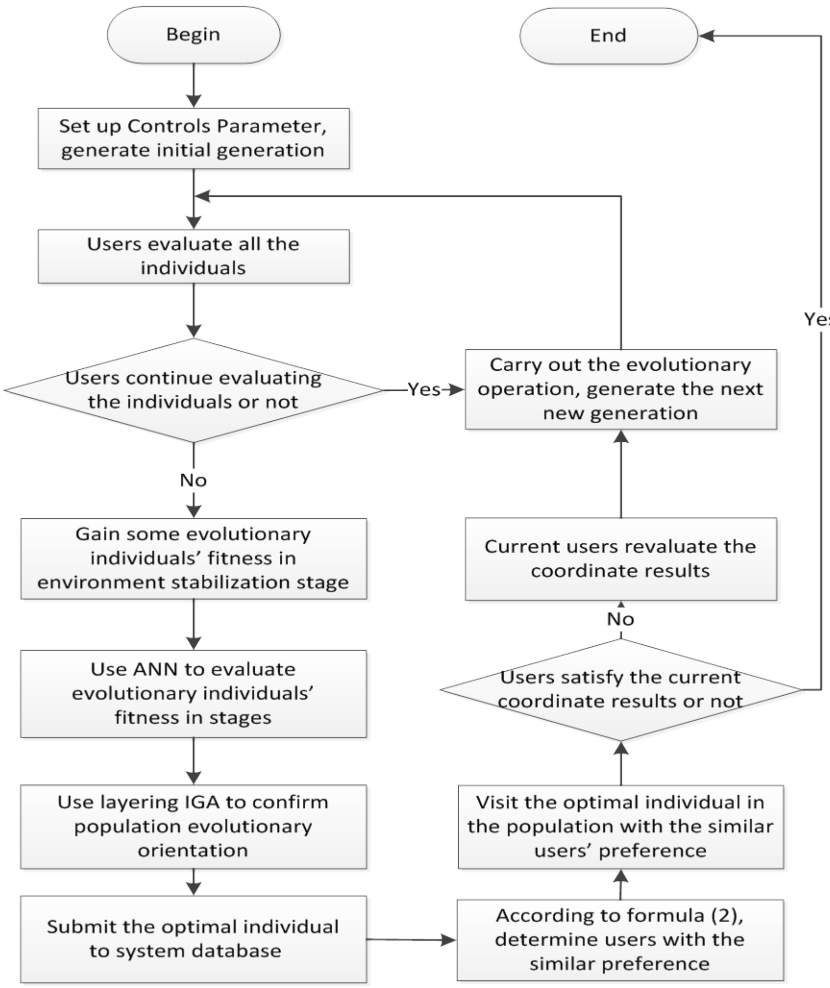


Fig. 3. Algorithm Flow