Interaction based Human Adaptive Conceptual Design Support System

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Abstract - This paper describes a human adaptive conceptual design system which designs the shape of a couple of Tableware. In the system, a framework of human adaptive approach is implemented based on the interaction between human and the system, by means of Interactive Evolutionary Computation. Users / beginner designers only carry out simple and subjective evaluation toward the automatically generated tableware shape by the system. The system re-generates the shape of tableware based on users' evaluation results, and presents users again. Repeating the interaction, users acquire satisfied design. The system uses rules of linguistic feature expression of the tableware's shape. Also, the system preserves rules, which are evaluated well by users, toward Database. Therefore, the users' own conceptual favorite shape features are preserved. These rules can be repeatedly applied in order to generate new kinds of tableware, which have the same concept.

I. INTRODUCTION

Recently, Computer Aided Design (CAD) is known well in the field of product design. In CAD system, technical learning and experience are still needed toward designers. This fact makes high hurdle for beginner designers. On the one hand, the product designers are made much of individual preference. In order to meet these needs, conceptual design, which considers human feeling or Kansei, is paid more attention \cite{1}. The conceptual design is the action which is carried out at earlier step in the product design, and it realizes what designers (or target consumers) want toward products, in the conceptual level \cite{2}. In order to produce smash hit products, which have strong brand image among consumers, it is needed to determine consistent design concept. If an impression of different kinds of product series' shape is the same, the consistent conceptual image is added toward them. Based on this assumption, this study focuses the products' shape, and aims to support beginner designers' conceptual design of a series of products' shape.

This study proposes an interaction based human adaptive designing system. In this framework, the features in the shape between two products are optimized by means of Interactive Evolutionary Computation algorithm. Through the framework, users/designers search the good products, which reflect the users' feeling or Kansei, and they acquire concept to create several kinds of products. After the concept is acquired, they are applied to another product in order to design products which have the same concept.

In this study, the Interactive Genetic Algorithm (IGA) is introduced to the system. The IGA with human subjective evaluation, which is instead of fitness function, is applicable to the fields such as arts or industrial design \cite{3}\cite{4}. In this paper, the objective product is fixed as several kinds of tableware, and the design support system generating pairs of tableware using IGA, is mainly described.

In the chapter II, proposed framework by means of interaction is described. System architecture and detail of proposed system is described in the chapter III and IV. The advantage of the proposed system is discussed in the chapter V. And, conclusion and future works are described in the chapter VI.

II. FRAMEWORK OF CONCEPTUAL DESIGN SUPPORT

In this system, a framework of conceptual design support is divided as two steps as shown in fig.1. In this paper, step of design generation and concept acquisition is mainly described.

A. Step 1: Design Generation and Concept Acquisition

In the first step, the proposed system randomly generates plural number of a pair of products. In this paper, the products are fixed as tableware, which we use in the daily life. In this step, users acquire a pair of tableware’s shape by repeating interaction between the system's generation and users' subjective evaluation of the candidates. And the system acquires physical feature rules of some parts and points of the products as linguistic expression. In this step, the IGA is introduced. The solution is searched the problem space, based on interaction between users and system. The interaction is composed by users' evaluation from subjective viewpoint and the system's re-generation based on the evaluation result. In this paper, the system generates two kinds of tableware as candidates (genes). Performing the interaction, users acquire a pair of tableware, which reflects users' conceptual image.

B. Step 2: Designing another Kinds of Products Using the Same Conceptual image

In the second step, users and the system try to generate another (new) kind of tableware, which reflects the same conceptual image, which is acquired at the first step. In this step, the common rules database, which as mentioned in
chapter IV, is used as information of users conceptual image. The IGA based interaction between users and system is also introduced in this step.

Fig.1. Framework of Conceptual Design Support

III. SYSTEM ARCHITECTURE

A. Conceptual Designing Support by Selecting Linguistic Feature Expression Rules

In this study, we assume the situation, which users don’t have any concept of generating products, at the beginning of using proposed system. Therefore, the users gradually confirm their own concept by the interactive search between users and the system. At the optimization viewpoint of the product design, the Concept is the knowledge information for conditioning search space of design candidates. If the system has a certain number of rules which represents feature of the shape, and these rules are selected based on users’ subjective preference, then the confirmed rules are the rules, which reflect the users’ own Kansei image.

We also assume that the users’ own Kansei image is needed to express by combination of linguistic information, such as “lower width is wide” and “handle is small”, and so on. Therefore, in this study, the feature expressing rules are used when generating the shape of products. These rules are composed by means of fuzzy sets, and they connects linguistic feature expression and parametric expression of shape,

B. Flow of the Conceptual Design Support System

Based on the adaptive support of acquiring users’ Kansei rules, the interaction flow between the proposed system and users is shown as Fig.2.

Firstly, users select two kinds of product and begin interaction considering vague concept to design the products’ shape, such as the situation used the products, or the target people that will use the products. In this step, users’ conceptual image is not confirmed and has not been reflected in the physical attribute of the products yet.

1) Generation and Presentation of Design Candidates

The system generates one hundred kinds of candidates randomly based on the feature expressing rules. Then, nine kinds of candidates’ shape are presented to users through the user interface. In the interface, a one candidate is displayed as a pair which has two kinds of candidates. In this paper, the candidates are fixed as tableware.

2) Users’ Subjective Evaluation of Candidates

Users perform subjective evaluation toward presented candidates through the interface, based on the users’ own Kansei image.

3) Selection of Common Feature Expressing Rules

The system analyzes feature expressing rules, which users evaluated through the interface. The system selects common feature expressing rules, which are evaluated as good by users. Then, the system gives evaluation values toward the selected common rules, and adds to the common rules database.

4) GA Operators and Generation of New Candidates

The system applies GA operators toward candidates, based on the users’ subjective evaluation results, and one hundred kinds of new candidates are generated.

5) Application of Common Rules from Database

The system randomly selects a certain parts of common feature expressing rules from common rules database considering the evaluation value that is given each rule, and applies the rules toward parts of newly generated candidates.

6) Representation of newly Generated Candidates

The system presents newly generated nine candidates again through the interface.

7) Acquisition of Satisfied Candidates

If users acquire satisfied candidates which reflect users’ Kansei images, the iteration is stopped.

8) Application toward New Kinds of Products’ Feature

The common feature expressing rules, which are stocked in the common rules database, are applied toward new kinds of candidates, because of the feature expressing rules are constructed as linguistic feature.

Operators 4), 5), and 7) are so-called suggestion toward users as the designing support system. And, these are based not on GA operator’s probabilistic operators, but the trial of direct shape manipulation which is based on the users’ tacit taste, or Kansei image.

User

4) GA Operators and Generation of New Candidates

System

3) Selection of Common Feature Expressing Rules

5) Application of Common Rules from Database

1) 6) Generation and Presentation of Design Candidates

7) Acquisition of Satisfied Candidates

8) Application toward New Kinds of Products’ Feature

Common (Good) Rules DB

Fig. 2. Flow of the Interactive Conceptual Design Support System
IV. SYSTEM COMPONENTS

A. Composition of Tableware and Linguistic Expression of Features

In this paper, physical parameters representing the shape of tableware are composed as coordinate points in the two dimensional space. The shape is composed by randomly determination of several number of XY-coordinate points in the two dimensional space as shown in Fig.3. Furthermore, the shape information can be converted to linguistic expression concerning the feature of the shape, using the following three steps as shown in Fig.4.

1) Generation Shape as 2D Vector

The system randomly determines the combination of XY coordinates. In this step, the curves of the shape are calculated as Bezier-curves.

2) Parametric Expression of Each Part

The parametric expression, which can be included the feature of parts, are prepared as shown in Fig.4. The system calculates those parameter values (scalar quantity).

3) Linguistic Expression of Features

The Conversion Rules between the parameter values in the step 2 and the linguistic expression of features are prepared, which are called as feature expressing rules in this paper. Using these rules, the system converts from parameter value(s) to a fuzzy membership value, which represents a linguistic expression of feature.

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### Example of Feature Expression

- **The side shape is straight.**
- **The lower part is wide.**
- **The bottom is narrow.**

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B. Feature Expressing Rules

Partial linguistic expressions of shape are needed as factors of which users can determine consistent concept. To this end, we prepare the rules called feature expressing rules, which connects between physical information and linguistic information.

Table 1 shows the example of feature expressing rules of cup, which has body and handle. In the rule of each row, one linguistic expression of feature in a certain part of a cup is configured with four values of trapezoidal membership function parameter of fuzzy sets, which is arranged as shown in Fig.5. In a certain cup, each rule has a membership value ([0.0, 1.0]), which represents the degree of the linguistic label. These linguistic features in the Table 1 are prepared by one physical parameter or plural numbers of parameters.

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![Fig.5. Fuzzy Membership Function Setting in the Feature Expressing Rules](image)

C. Chromosome of IGA

In this system, the tableware shape is mainly designed by means of operators of Interactive GA. It is important for the system to inherit good characteristics of parents to the next generation children. To avoid generating worse or mortal candidates, this system uses feature expressing rules directly, as coding of chromosome.

In this paper, one candidate means a pair of products (tableware), as shown in Fig.6. So, one candidate has two kinds of chromosomes, which has information of each kind of product. The loci of the chromosome correspond to feature expressing rules as shown in Table 1. The system generates one hundred kinds of candidates with random parameters, and each value in each locus is calculated using fuzzy membership functions.

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![Fig.6. Example of Candidate with Two Kinds of Chromosomes](image)

D. User Interface and Subjective Evaluation

The system presents nine kinds of candidates through the user interface as shown in Fig.7. In the upper part of the UI, presented candidates are displayed. Users watch at each pair and perform two kinds of subjective evaluation.

1) Evaluation of Each Pair

Users evaluate the objective image of concept with 4 scales,
such as “very good”, “good”, “so-so”, or “bad.”

2) Selection of Best Pair

Users compare the pairs that are evaluated “good”, and select the best pair as “favorite pair.” The selected pair is displayed in the lower part of UI at the next generation. These favorite pairs increase one by one as the generation passes. If the users cannot find better pair from the presented candidates, users choose one from favorite pairs displayed.

E. Common Rules Database

The database called common rules database is prepared in this system. In this database, the feature expressing rules and the evaluation value is stocked. These rules represent commonly appeared feature of the user’s favorite shapes.

1) Extraction of Good Rules

From the presented candidates, the “good” or “very good” evaluated candidates’ feature expressing rules are extracted. In this paper, the rules of whose membership value is more than 0.6 are extracted.

2) Determination of Evaluation Value of Extracted Rules

The evaluation value of the rule is determined. The value is the number of candidates, which has the same rules which is extracted.

3) Add Rules toward Database

If the evaluation value is more than two (i.e., there are more than one common rules in another candidates), then the feature expressing rules and the evaluation value is added to the common rules database.

4) Update Database

The evaluation value of each rule in database is updated at every generation. The procedure is the same as step 2.

F. Generation of New Candidates Using GA Operators

The system applies GA Operators in the following steps, and generates new candidates.

1) Determination of Next Generation Parents

The system generates one hundred kinds of next generation parent candidates in the pool, using below mentioned procedures.

1. The candidates, which is evaluated as “very good”, “good”, or “so-so”, is copied with nine, six, or three, respectively.
2. The candidate, which is chosen as favorite pair, is copied with nine.
3. The remaining number of candidates for 100 is chosen randomly from the candidates, which is not presented to users.

2) Crossover

The crossover operator is applied to the parents with below mentioned steps. The probability of crossover is assumed to be 0.5.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Instrument</th>
<th>Region</th>
<th>Feature Extracted Parts</th>
<th>Feature Extracted Factors</th>
<th>Linguistic Expressions of Feature</th>
<th>Fuzzy Membership Function Expressions</th>
<th>Related Parameters</th>
<th>Related Coordinates</th>
<th>Influencing Parameters</th>
<th>Locus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CUP Body</td>
<td>lower bottom part width</td>
<td>thin</td>
<td>(30,30,30,53)</td>
<td>w1 a1,a2</td>
<td>w1,w2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CUP Body</td>
<td>lower bottom part width</td>
<td>normal</td>
<td>(53,75,75,98)</td>
<td>w1 a1,a2</td>
<td>w1,w2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CUP Body</td>
<td>lower bottom part width</td>
<td>thick</td>
<td>(100,125,125,125)</td>
<td>w1 a1,a2</td>
<td>w1,w2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>CUP Body</td>
<td>bottom part width</td>
<td>thin</td>
<td>(25,25,25,50)</td>
<td>w2 a2,a1</td>
<td>w2,w1</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CUP Body</td>
<td>bottom part width</td>
<td>normal</td>
<td>(50,75,75,100)</td>
<td>w2 a2,a1</td>
<td>w2,w1</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>CUP Body</td>
<td>bottom part width</td>
<td>thick</td>
<td>(100,125,125,125)</td>
<td>w2 a2,a1</td>
<td>w2,w1</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>CUP Body</td>
<td>bottom part height</td>
<td>low</td>
<td>(10,10,10,15)</td>
<td>h1 a1,a2</td>
<td>h1</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>CUP Body</td>
<td>bottom part height</td>
<td>normal</td>
<td>(15,20,20,25)</td>
<td>h1 a1,a2</td>
<td>h1</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>CUP Body</td>
<td>bottom part height</td>
<td>high</td>
<td>(25,30,30,30)</td>
<td>h1 a1,a2</td>
<td>h1</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>CUP Body</td>
<td>lower middle part breadth</td>
<td>getting narrow</td>
<td>[-30,-30,-30,-15]</td>
<td>w4-w5</td>
<td>a4</td>
<td>w4, all tw</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>CUP Body</td>
<td>lower middle part breadth</td>
<td>normal</td>
<td>[-15,0,0,15]</td>
<td>w4-w5</td>
<td>a4</td>
<td>w4, all tw</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>CUP Body</td>
<td>lower middle part breadth</td>
<td>getting wide</td>
<td>[15,30,30,30]</td>
<td>w4-w5</td>
<td>a4</td>
<td>w4, all tw</td>
<td>51</td>
<td></td>
<td></td>
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<tr>
<td>64</td>
<td>CUP Body</td>
<td>whole part height</td>
<td>low</td>
<td>(50,50,50,175)</td>
<td>h1+h2+h3</td>
<td>a1-a8</td>
<td>h1---h7,all hh</td>
<td>64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>CUP Body</td>
<td>whole part height</td>
<td>normal</td>
<td>(175,300,300,425)</td>
<td>h1+h2+h3</td>
<td>a1-a8</td>
<td>h1---h7,all hh</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>CUP Body</td>
<td>whole part height</td>
<td>high</td>
<td>(425,550,550,550)</td>
<td>h1+h2+h3</td>
<td>a1-a8</td>
<td>h1---h7,all hh</td>
<td>66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>67</td>
<td>CUP Handle position</td>
<td>height</td>
<td>low</td>
<td>(20,20,20,40)</td>
<td>h1</td>
<td>h1</td>
<td>h1</td>
<td>67</td>
<td></td>
<td></td>
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<tr>
<td>68</td>
<td>CUP Handle position</td>
<td>height</td>
<td>normal</td>
<td>(60,60,60,60)</td>
<td>h1</td>
<td>h1</td>
<td>h1</td>
<td>68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>69</td>
<td>CUP Handle position</td>
<td>height</td>
<td>high</td>
<td>(80,100,100,100)</td>
<td>h1</td>
<td>h1</td>
<td>h1</td>
<td>69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>CUP Handle whole part height</td>
<td>low</td>
<td>(80,80,80,80)</td>
<td>h1</td>
<td>h1</td>
<td>h1</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>71</td>
<td>CUP Handle whole part height</td>
<td>normal</td>
<td>(80,100,100,100)</td>
<td>h1</td>
<td>h1</td>
<td>h1</td>
<td>71</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>72</td>
<td>CUP Handle whole part height</td>
<td>high</td>
<td>(120,140,140,140)</td>
<td>h1</td>
<td>h1</td>
<td>h1</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
be 70% of candidates.  
1. Candidates A and B are chosen from the parents randomly.  
2. One locus is chosen from chromosome A or B in the candidate A randomly.  
3. The chosen locus is copied to the corresponding kind of chromosome in candidate B.  
4. Corresponding parameters of tableware in the chosen locus are replaced.  
3) Mutation  
The mutation operator is applied to the parents with below mentioned steps. The probability is assumed to be 10% of candidates.  
1. Candidate A is chosen from the parents randomly.  
2. One locus is chosen from chromosome A or B in the candidate A randomly.  
3. Corresponding parameters of tableware in the chosen locus are newly determined randomly, and replaced.  
4. Corresponding parameters of tableware in the locus are replaced.  

G. Reflection Common Feature Rules toward Parameters  
The system applies common feature rules from the database, which are saved as users’ good evaluated future, toward the newly generated candidates. The following procedure is applied for ten percent of candidates.  
1) Choose Common Feature Rules  
The system chooses a rule from common rules database randomly. A probability of choosing $i$-th rule $p_i$ from all rules is (1), where $v_j$ is evaluation value of $j$-th rule.  
\[
\begin{equation}
    p_i = \frac{v_i}{\sum_{j \in N} v_j}
\end{equation}
\]

2) Apply Common Feature Rules  
The system applies chosen rule toward randomly selected candidates’ locus, and the parameters of a certain part of product is randomly modified so that applied common rules are fired. For example, if the rule is “the LOWER PART of CUP’s WIDTH is THICK”, then the parameters concerning the lower part of cup are randomly modified so that the values concerning width belong to “THICK”. That is, the fuzzy membership of the linguistic expression is more than 0.5.  

H. Representation of Next Generation Design Candidates  
Nine candidates are randomly chosen from newly generated candidates, and they are presented toward users again through the interface.  
Repeating interaction between users and the system, the users acquire satisfied shape of products.  
On the one hand, the favorite shape feature is stocked in the common rules database. These rules can be applied as the confirmation or clarify users’ own image of conceptual design products. And, if another kinds of products need to be generated, these rules are used as information of generating shapes, which has the same conceptual image that is acquired at before repetition.  

V. DISCUSSION  
In order to confirm proposed system’s advantage from objective point of view, the difference between related works and proposed system is discussed in this section. And the advantage from viewpoints of Kansei Information Processing System and Kansei engineering oriented design technique is also discussed in this section.  
A. Related Works and Proposed System  
There are several kinds of related works in the field of product design support system, which design products’ shape. It is known as Computer Aided Design (abbreviated as CAD).  
Yanagisawa et al. propose interactive evolutionally algorithm which searches preferential automobile shape based on attractive points [5]. In the work, attractive points are contracted by quantitative similarity of shape using rough set theory. Our study is different from the study at a viewpoint that a users’ subjective feeling is considered when the characteristics are obtained.  
Doi et al. develop an educational CAD system, which is used as apparel design [6]. Interactive Evolutionary Computation technique is used in this work. This system is developed not as feeling-based design system, but as an educational point of view.  
Nagata et al. develop a design system based on concept space expressing Kansei [7]. In the system, the operation queues, which transform the object’s shape, are generated by Case Based Reasoning (CBR). In the work, a common feature from images is considered when generating products. The purpose of our study is to reflect subjective feeling toward products, and common feature information of products that belong to individual is implemented using common rules database. Therefore, user’s subjectivity gets more important than Nagata’s system.  
B. Viewpoint of Kansei Information Processing System  
Nowadays, the field of Kansei Information Processing System is widely recognized. Furthermore, in the field of product design, Kansei engineering oriented designing technique is one of the well-known techniques to consider many kinds of factors, such as human complex and subjective Kansei (or feeling) [1]. Kansei engineering oriented design technique is one of the total techniques of designing products, which is formed the steps from human emotional aspects to shape of products. Kansei engineering is concerned in psychology at the step to which designers catch customers’ mental image, and concerned in ergonomics at the step to shape products from the image. Actually, the design process is applied not to an entirely new product but to the shape of existing products. In this case, the designer realizes the final shape of the products to fill objective concept with his/her emotional image. In this study, this kind of product design is considered.  
The approach of proposed framework is original from the point of view that users perform evaluation toward candidates based on subjective Kansei image (or feeling), and the system connects between users’ concept and physical attribute of products. In the proposed system, the connection approach by
IGA is the original approach at the field of CAD system. In
the interaction, users' subjective evaluation is reflected to the
linguistic expression of feature of the products' shape by
feature expressing rules. They are easy to add or modify, if a
new physical attribute is needed for a new product design.
And, by using the rules, the partial evaluation by users toward
the feature of a certain part is comparatively easy to
implement. Furthermore, this paper proposes individual
database that is named common rules database. The
information in the database is easy to recognize the user's
taste or demands for new products with the same concept.
This kind of information processing is realized by linguistic
information using fuzzy sets.

VI. CONCLUSION AND FUTURE WORK

This study aims to support beginner designers’ consistent
design of a series of products, by means of Computer Aided
Design of the products’ shape. This study proposed a new
framework by means of IGA, which performs interaction
between users and the system through the generation and
presentation of candidates (designed products). Users'
subjective evaluation information toward candidates, which is
considered a certain concept of design, is used in generating
new shape of products. In this technique, the feature
information of the shapes is considered. Through the
framework, users/designers search good products which
reflect users' Kansei image, and they acquire concept, which
can be used to create several kinds of another products with
same concept. Our future work is to confirm the validity of
the system by performing subjects’ experiments.

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