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Development of a Rule-Based Inference Model for Human Sensibility Engineering System

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Human Sensibility Engineering System (HSES) has been applied to product development for customer's satisfaction based on ergonomic technology. The system is composed of three parts such as human sensibility analysis, inference mechanism, and presentation technologies. Inference mechanism translating human sensibility into design elements plays an important role in the HSES. In this paper, we propose a rule-based inference model for HSES. The rule-based inference model is composed of five rules and two inference approaches. Each of these rules reasons the design elements for selected human sensibility words with the decision variables from regression analysis in terms of forward inference. These results are evaluated by means of backward inference. By comparing the evaluation results, the inference model decides on product design elements which are closer to the customer's feeling and emotion. Finally, simulation results are tested statistically in order to ascertain the validity of the model.

Key Words : Human Sensibility Engineering, Rule-based Inference Model, Computer Simulation

1. Introduction

The development of production technology has made our society materially affluent and mentally fastidious in these days. It has also changed industrial environments into unlimited varieties, rapid changes and global competitions. Among these changes, the variety of customer demands has a significant influence on production process and product design concepts. Customer demand and preferences have forced manufacturers to reduce the increased workload caused by the diversification of the products. This has resulted in the change of production process from mass production to multi-product small-sized lot production (Yang and Lee, 1996).

In proportion to the satisfaction of basic requirements such as quantity, quality, and price, customers yearn not only for goods that satisfy their physical requirements but also those which are valuable to their desire and would fulfill their psychological needs such as feeling and emotion. This has forced a shift in production strategy and the product design concept.

Generally, products have two properties. One is the basic function of the product which is determined by quality, capacity, and performance satisfying the customer's basic requirements (Park and Seo, 2003). The other is the subsidiary function of the product is imported by shape, style, and color appealing to the customer's mind. We regarded the former as physical factors and the

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letter as mental factors. According to the technical development, the differences in the basic functions between products have become narrower, but on the other hand the subsidiary functions of the product have become important factors in appealing to the customers. Thus, customer-oriented concept has become one of the very important strategy from the viewpoint of comprehending and fulfilling customer's desires and demands.

When customers purchase goods in the market, they search for goods that appeal to their own preference and convenience. They present their desires by abstract adjectives. Therefore, it would be very beneficial for the manufacturers if they can catch customer's thought and can show them the models which are well fitted to their image through photographs or computer graphics. In this situation, it is very important to analyze human senses (hereafter human sensibility) such as feeling and emotion and to translate this information into proper design elements in the development of a new product. Nagamachi has taken concrete shape about this idea and has developed "Human Sensibility Engineering (HSE) (called "Kansei Engineering" in Japan)" as an effective technology for the purpose of supporting customer's decision making and designer's creativity (Nagamachi, 1986, 1988, 1989). HSE, as a kind of human ergonomic technology, can be defined as a methodology for translating human psychological processes such as feeling and emotion related to products into appropriate product design elements such as size, shape, and color. "Kansei" is a Japanese word which means a customer's psychological feelings and image regarding a product. It has recently attracted much attention as an effective tool for both customers and the product designers, and has been applied to various product developments.

There are two kinds of approach in the HSE. One is the category classification method which is a break down technique from an abstract design concept for a new product to some concrete design elements sequentially (Nagamachi, 1992). Designers or manufacturers define the product concept with some words or sentences as zero level and then level down that concept to the final stage in which real design elements are identified precisely.

The other approach is a computer-based decision supporting technique (Nagamachi, 1994c; Matsubara et al., 1994). The HES is composed of three major parts: (1) collection and analysis of human sensibility words presenting human senses related with product image, (2) inference the relationship between human sensibility and product design elements, (3) presenting the inference results by means of computer graphics.

Of these, logic or algorithms in inference mechanism (Shim and Suh, 2002) plays a key role in the whole processes of the HSES. Thus, it is important to satisfy the above three aspects in order to be effective in practice. First, inference logic must reflect all of the human sensibility words selected by customers with equal emphases in translating them into design elements. Second, reasoned results by inference logic can show some obvious differences between selected words and the other words in terms of the whole aspects of the product rather than one or two product elements. Finally, inference logic must give high reliability in order to reduce the difference of product image between the customer's desire and the reasoned results.

In this paper, a new rule-based inference model satisfying the above requirements is proposed. This model consists of two procedures. One is to reason product elements by five rules through forward inference and the other is to decide the most appropriate result by comparing the results reasoned from five rules through backward inference. Decision variables used in this model are based on some statistical results gained by the Hayashi's Quantification Theory Type I which is a kind of linear regression model (Hayashi, 1976).

The landscape design has also become one of the interesting research fields in the HSES because it has influence on human living style physically and mentally in everyday. We apply the HSES to the landscape evaluation in order to support designers' creativity. As an experimental study, the evaluation of river landscape design is applied in this paper. The effectiveness of the proposed model is experimented through the application to the evaluation of river landscape design.

The paper is organized as follows : In section 2, the HSE is overviewed. The proposed rule-based inference model is described in section 3. In section 4, an experimental study is performed in order to evaluate the rule-based inference model. The human sensibility evaluation for the river landscape is shown as an example. Finally, some conclusions and future works are presented in section 5.

2. Overview of the Human Sensibility Engineering

2.1 System structure

The HSES is composed of three subsystems : human sensibility analysis, human sensibility inference, and human sensibility presentation. Figure 1 (Nagamachi, 1995b ; Han et al., 1996) shows the whole structure of the three subsystems.

The first subsystem is to collect human sensibility words proper to the domain of design object, and to analyze people's feelings and emotion presented by words and to quantify them into some numerical values. Semantic Differential (SD) method is used for evaluating the appropriateness of human sensibility words about the domain of design and for quantifying its qualitative properties (Osgood, 1957). Factor analysis is performed in order to investigate meaning space for human sensibility words based on SD evaluation. The main goal of the first subsystem is to construct human sensibility database whose attributes are human sensibility words and some quantitative values having the correlation properties between human sensibility words and design elements. Hayashi's quantification theory type I is used to get correlation properties, which is an effective regression method to deal with values with qualitative and quantitative properties (Hayashi, 1976).

The second subsystem is to translate the people's image into concrete design specifications. There are various kinds of inference models for the translation process. Various mathematical theories such as heuristics, fuzzy theory, neural network theory and genetic algorithm have been also introduced in the inference models. These models use the information stored in human sensibility database as input parameters in the reason process (Shimizu et al., 1995 ; Ishihara et al., 1995 ; Tsuchiya et al., 1996).

The third subsystem is to present the reasoned design elements in the inference model with gra-

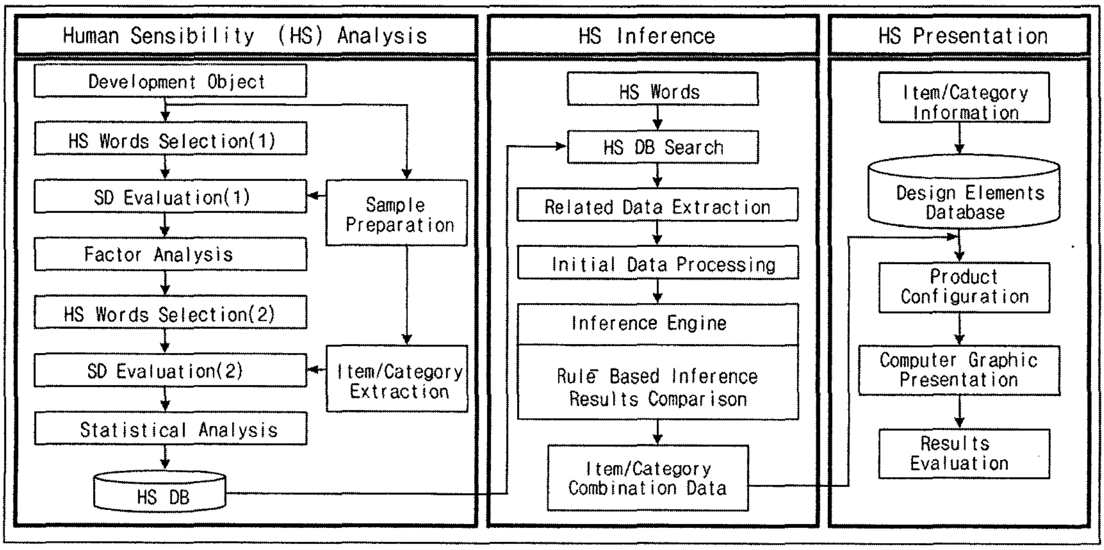


Fig. 1 The architecture of the HSES

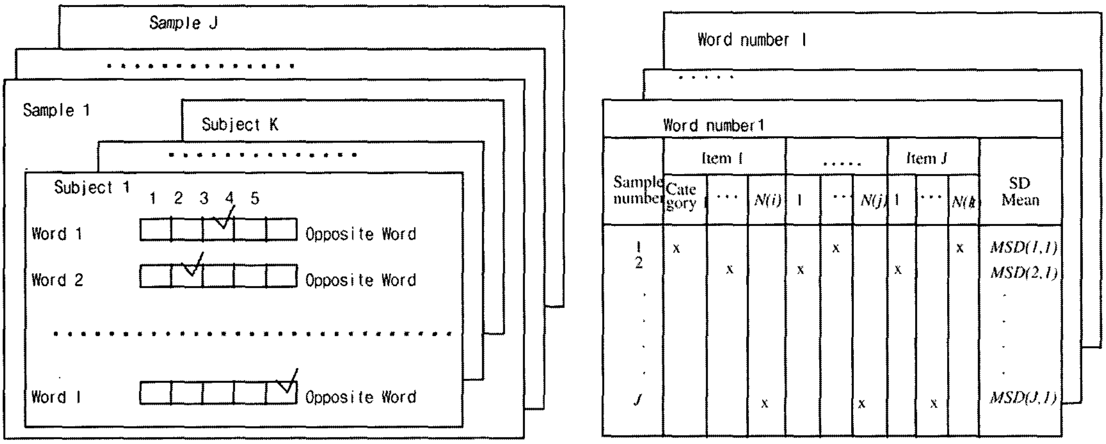
phic technologies and to identify technical function of the design object. As effective presentation tools, two or three dimensional graphic techniques and virtual reality technology has been used (Imamura et al., 1994 ; Matsubara et al., 1997a).

2.2 Quantification procedures

The quantification procedure is to analysis human sensibility and translate its qualitative information into quantitative information. The preparation of quantification is to change customer's feelings and emotions into proper numerical data. The Semantic Differential (SD) method developed by Osgood is a typical procedure for getting meaning space from well-prepared samples by investigation of the numerical mapping relationship between the samples and the related words. It uses numerical scales such as 5-grade serial numbers or 7-grade serial numbers for evaluation measure (Osgood et al., 1957).

In HSES, SD is also used for gaining meaning space between human sensibility words and product design elements. For this evaluation, it is necessary to prepare human sensibility words, design samples, and subjects carefully. Human sensibility words can be collected from magazines, catalogues, conversations between customers and sellers. Design samples must be prepared in order that categories on each item do not overlapped each other for mathematical analysis. In order to analysis quantitatively, design samples must be divided into items which have distinctive characteristics among the components consisting of the whole figure of product. The items must again divide into several categories which present the specifications of each item. Subjects must be chosen be representatives for the target customer group. The subjects check a point among the scaled numbers that they think appropriate to the pictures presented in front of them on each human sensibility word and each sample on the prepared sheets, as shown in Figure 2(a).

The quantification procedure is performed into two steps. The first one is to evaluate the suitability about many human sensibility words collected from various kinds of source. Factor analysis is introduced for compressing information into a smaller number of synthesized variables and for finding axes of semantic space after this SD evaluation. Human sensibility words are mapped in the semantic space based on their principal component loading and are grouped together. Through the factor analysis, human sensibility words are summarized from hundreds of words into several score of ones. These words are used again in the SD evaluation which is to analyze the relationship between each of words and subject's image about each sample. The sequential scaled numbers provide quantitative information on each human sensibility word. We can define S^{λ}_{ij}



(a) (b)

Fig. 2 SD evaluation for human sensibility words and its formation for regression as SD scores for subjects, where λ is design sample number, i is human sensibility word number, and j is subject number. We can also define SM_i^λ for each word on each samples. It can be obtained by averaging the checked number across subject as follows, where n is total number of subjects.

$$SM_i^\lambda = \sum_{j=1}^{n} S_{ij}^\lambda \tag{1}$$

The next step in the quantification procedure is to estimate the relationship between human sensibility words and product design elements by means of regression methods based on the assumption of linearity. The linear multiple regression analysis is a method to derive certain relationships between one value y which is called a criterion variable (dependent variable) and variables x_1, x_2, $\cdots$, x_n which are called explanatory variables (independent variables). The criterion variables and the explanatory variables have quantitative values with interval scale in the general regression analysis. But, there are many cases to analyze the relationship between criterion variables having qualitative properties and explanatory variables having quantitative ones in our environments. Hayashi's Quantification Theory Type I is well known as an effective method to deal with such cases (Tanaka, 1983). In case of HSE, the major role is to analyze the relationship between human sensibility having qualitative properties and design elements having quantitative properties. Thus, it can be used as an effective regression method in the HSES. The general regression model of the Hayashi's Quantification Theory Type I can be define as follows on each human sensibility words i, where j is item number, k is category number (Kawaguchi et al., 1980).

$$y^\lambda = \sum_{j=1}^{m} \sum_{k=1}^{c_j} a_{jk}^\lambda + e^\lambda \tag{2}$$

where $j=1, 2, \cdots, m$ (m is the number of items) and $k=1, 2, \cdots, c_j$ (c_j is the number of categories on item j).

In the above equation, a_{jk} is called partial regression coefficients or category scores (weights). The major goal of the equation is to find coefficients a_{jk} in order to minimize of the deviation between estimated values and real values. y^λ and x_{jk}^λ are called criterion variables and explanatory variables, respectively. The estimated values of a_{jk} can be obtained by solving simultaneous equations composed by above equation. For example, if there are fifty samples, fifty simultaneous equations can be formulated on each word.

In HSE, each item have only one category on each sample. Thus, it is necessary to introduce dummy variables to explanatory variables x_{jk}^λ. Practically, a criterion variable y^λ corresponds to SM_i^λ gained from SD evaluation and explanatory variables x_{jk}^λ have 0 or 1 according to the composition of the design elements on each samples. By solving simultaneous equations, we can get three important variables which is used as parameters in our inference model. These are multiple correlation coefficients, partial correlation coefficients, and category scores. Figure 3 shows the relationship of these values with human sensibility words and design elements.

Multiple correlation coefficients give the degree of relationship between a human sensibility word and the product image. It is said to be a very suitable word if the value is close to 1. Partial correlation coefficients give the degree of closeness between a word and each item. If the value for some item is higher than that of any other items, it can be said that the latent meaning of the word is closer to that item than any other items. Category scores mean the degree of contribution

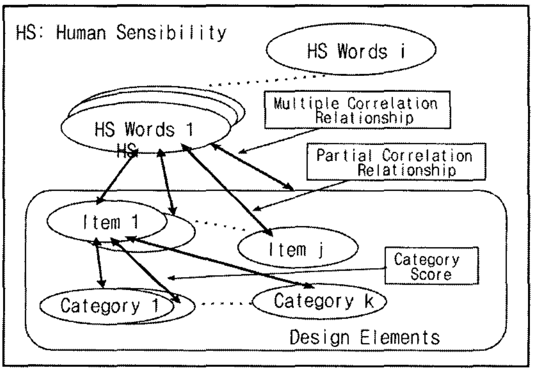


Fig. 3 The relationship of parameters

of each category of each item to a human sensibility word. These three values can have statistical validity because these values are obtained by regression analysis. This needs two kinds of statistical test for this reason. One is the F-test for regression model and the other is t-test for parameters such as partial correlation coefficients and category scores.

2.3 Inference methods

There are two kinds of the inference method in the HSES as shown in Figure 4 (Matsubara et al., 1997b).

One is forward inference and the other is backward inference. Forward inference is used to reason the product design elements from human feeling and emotion. In other words, the goal of this procedure is to find the product design elements which are the most close to the human sensibility words given by customers. It is utilized to support the customer's decision making in selecting a product which satisfies his or her own preference.

On the other hand, backward inference is used to diagnose how well each human sensibility word presents the image of the given product design elements. Through the diagnosis by backward inference, the degree of closeness between human sensibility words and design elements can be analyzed. When some design elements are figured by designers, it is possible to get the human sensibility words which have the most influence on the design elements by this approach. Thus, this approach is useful for supporting designers in doing his creative works.

It can be said that an inference model is highly reliable if the results from forward inference and the ones from backward inference give almost the same information to the customers and to the designers. Therefore, this idea can also be used to test the reliability or validity of an inference model. It is also possible to investigate whether there are discriminations between selected words and any other words of design elements. We use this idea in finding the effectiveness of inference rules designed in this paper.

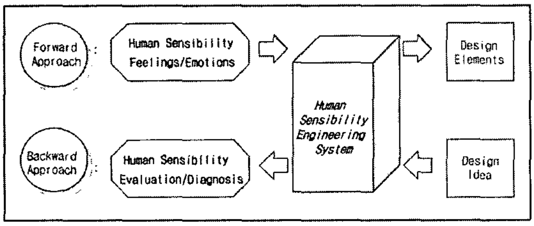


Fig. 4 Inference procedures in the HSES

3. Rule-based Inference Model

The rule-based inference model proposed in this paper has five reasoning rules, and is composed of three procedures such as standardization, reasoning, and comparison procedures, as shown in Fig. 5.

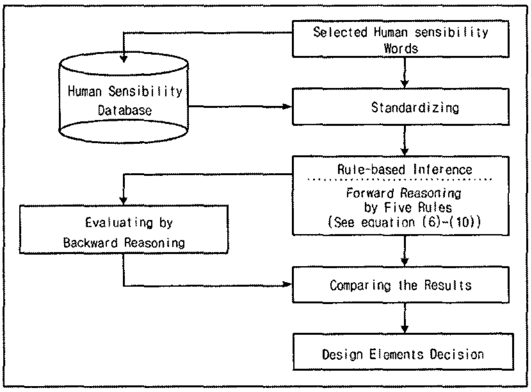


Fig. 5 Rule-based inference procedure

3.1 Standardization of the quantified data

The values gained from Hayashi's Quantification Theory Type I have different range on each human sensibility words. Especially, partial correlation coefficients and category scores are restricted its meaning within one word. The difference can cause to inadequate results in comparison process among words. Therefore, it is necessary to put the data into ones having same range in order to evaluate with same weight in the inference process. Standardization means the conversion of the partial correlation coefficients and category scores into the value between 0 and 1 in order to escape biased reasoning caused by difference ranges. Here, we redefine M_i, P_{ij}, C_{ijk} as multiple correlation coefficient of word i, partial correlation coefficient of item j for word i, and category score of category k for item j on word i. The standardization of P_{ij} is gained by the following equation, where SP_{ij} is a standardized value of partial correlation coefficient. As the same manner, SC_{ijk} also can be gained as standardized values of category scores.

$$SP_{ij}=\frac{P_{ij}}{P_{\max i}}, \text{ where, } P_{\max i}=\max\{P_{ij}\} \tag{3}$$

According to the above equation, all of the partial correlation coefficients have its value between 0 and 1. These standardized values become components of decision variables in rule 1, 2, 3, and 4. In case of category scores, the following equation is used for the standardization, where SC_{ijk} is a standardized value of category score.

$$SC_{ijk}=\begin{cases} 1, & \text{if } C_{ijk}=C_{\max_i} \\ 0, & \text{if } C_{ijk}=C_{\min_i} \\ (C_{ijk}-C_{\min_i})/(C_{\max_j}-C_{\min_i}), & \text{otherwise} \end{cases} \tag{4}$$

where $C_{\max_i}=\max\{C_{ijk}\}$, $C_{\min_i}=\min\{C_{ijk}\}$.

These values are used as parameters in the decision variables in all of the rules.

3.2 Reasoning rules and comparison procedure

Three decision variables are used in the inference rules. The role of decision measures is to provide a link between human sensibility words and design elements in terms of statistical relationship. Here, we introduce three decision variables such as $C1_{ijk}$, $S2_{ijk}$ and $S3_{ijk}$ for word i, item j, and category k as follows.

$$\begin{aligned} S1_{ijk}&=SP_{ij}\times SC_{ijk} \\ S2_{ijk}&=M_i\times SP_{ij}\times SC_{ijk} \\ S3_{ijk}&=M_i\times SC_{ijk} \end{aligned} \tag{5}$$

These variables, $S1$, $S2$, and $S3$ can be used as alternative decision variables according to the rules. The reason is that the relationship between human sensibility words and design elements is affected differently by the multiple correlation and partial correlation corresponding to the human sensibility words.

Rule 1 and 2 use $S1_{ijk}$ as decision variable. Rule 2 uses $S2_{ijk}$ as decision variable and $S3_{ijk}$ is used in rules 4 and 5. SC_{ijk} is used for a parameter in all equations. This is the reason that category scores have the most important meaning in estimating analysis.

The difference between M_i on each word can be large or small and the difference between SP_{ij} on each item can be large or small. When there is little difference between M_i on each of the words, partial correlation coefficients play an important role in reasoning process. In this case, $S1_{ijk}$ is an effective decision variable.

On the other hand, when there is little difference between P_{ij} on each of the items, the multiple correlation coefficients have influence on the reasoned results. In this case, $S3_{ijk}$ is an effective decision variable. This situation can vary according to the selected words and this is the reason why three decision variables are necessary.

There are some differences between rules in terms of forward reasoning. Rules 1 and 5 are composed of four steps with different decision variables. Step 1 and 2 correspond to forward inference. The first step is to select design elements which correspond to categories on each item for each selected human sensibility word.

The second step is to decide a category which is selected most frequently on each item by commonality and majority rules. In this paper, commonality means to identify that category which is selected most frequently and to decide that category as the final design element. Majority means that the rule uses multiple correlation coefficients as additional decision factor in case there are two or more categories with the same frequency. Steps 3 and 4 correspond to backward inference.

In order to draw backward inference, we define $R(r)$ as an intermediate value to get a comparison measure which is defined as $TR(r)$ on each human sensibility word with respect to the decided design elements.

〈Reasoning rule 1 and 5〉

Step 1 : for each selected word i,

(1) $j=1$

(2) $S1^*_{ijk}=\max\{S1_{ijk}\}$ for rule 1, and $S3^*_{ijk}=$

$\max\{S3_{ijk}\}$ for rule 5

(3) $j=j+1$

(4) if $j=1$ equals to the total number of item, then go to (5). Otherwise, go to (2)

(5) select a category for each selected word

Step 2 : for each item j,

(1) count the selected frequency for each category k

(2) $N1^*_k=\max\{N1_k\}$ for rule 1, and $N5^*_k=\max\{N5_k\}$ for rule 5, where $N1_k$ and $N5_k$ is the selected frequency in step 1.

(3) If there is k having unique maximum value, then, category k^* becomes a decision element otherwise, go to (4)

(4) decide category k^* with maximum value of Mi as a final decision element

Step 3 : for all human sensibility words,

(1) $R1_i=\sum_{j=1}^{m}S1^*_{ijk}$ for rule 1, $R5_i=\sum_{j=1}^{m}S3^*_{ijk}$ for rule 5

(2) find $\max\{R1_i\}$, $\min\{R1_i\}$, $\max\{R5_i\}$ and $\min\{R5_i\}$

(3) find $R1^*_i$ and $R5^*_i$, for r = 1 and 5

$$R(r)^*_i=\frac{[R(r)_i-\min\{R(r)_i\}]}{[\max R(r)_i-\min\{R(r)_i\}]}$$

Step 4 : find comparison measures for all selected words n

$$TR(1)=\frac{1}{n}\sum_{i=1}^{n}R1^*_i \tag{6}$$

$$TR(5)=\frac{1}{n}\sum_{i=1}^{n}R5^*_i \tag{7}$$

On the other hand, rule 2, 3, and 4 are composed of three steps. Step 1 decides design elements within each item previously cross the whole selected words. Each rule uses different decision variable and decide categories having maximum value. Backward inference is performed by step 2 and 3 like rule 1. The steps of the rules are as follows.

〈Reasoning rule 3, 4, and 5〉

Step 1 : for each item j

(1) $j=1$

(2) for rule 2

$S1_{ij}^{k*}=\max\{S1_{ijk}\}$ for selected words for rule 3

$S2_{ij}^{k*}=\max\{S2_{ijk}\}$ for selected words for rule 4

$S3_{ij}^{k*}=\max\{S3_{ijk}\}$ for selected words

(3) $j=j+1$

(4) if $j=1$ equals to the total number of item, then go to (5). Otherwise, go to (2)

(5) decide a category for each selected word

Step 2 : for all human sensibility words,

(1) $R2_i=\sum_{j=1}^{m}S1^*_{ijk}$ for rule 2, $R3_i=\sum_{j=1}^{m}S2^*_{ijk}$ for rule 3, $R4_i=\sum_{j=1}^{m}S3^*_{ijk}$ for rule 4

(2) find $\max\{R2_i\}$, $\min\{R2_i\}$, $\max\{R3_i\}$, $\min\{R3_i\}$, $\max\{R4_i\}$ and $\min\{R4_i\}$

(3) for $r=2, 3, 4$,

$$R(r)^*_i=\frac{[R(r)_i-\min\{R(r)_i\}]}{[\max R(r)_i-\min\{R(r)_i\}]}$$

Step 3 : find comparison measures for all selected words n

$$TR(2)=\frac{1}{n}\sum_{i=1}^{n}R2^*_i \tag{8}$$

$$TR(3)=\frac{1}{n}\sum_{i=1}^{n}R3^*_i \tag{9}$$

$$TR(4)=\frac{1}{n}\sum_{i=1}^{n}R4^*_i \tag{10}$$

According to the above steps, product design elements are reasoned by each rule and comparison measure on each rule is gained by backward inference. Finally, a rule is selected by a comparison procedure with the following equation and design elements are decided by the selected rule.

$$TR(r)^*=\max\{TR(r)\} \tag{11}$$

4. Experimental Study

An experimental study was performed in order to evaluate the rule-based inference model for river landscape evaluation as an example. It was performed with two steps. The one is to simulate

Table 1 Items and categories of the river landscape

Items	Categories
Riverside road	Curved, Straight
River width	Wide, Narrow
Sandbar	Grass, Ground, Stone and rock, Plants and ground, Tree
Bridge color	Red, Gray, White, Blue, No concern
Embankment	White concrete, Gray concrete, Concrete and plants, Stone and rock
Stairs	Existence, No existence
Guardrail	Existence, No existence
Around	Dwelling zone, Commercial zone
Building density	Low, High
Mountain	Near, Far, Near and far, Unnecessary
Water surface	0-20%, 21-40%, 41-60%, Over 60%
Bank type	1 stair, 2 stairs (wide), 2 stairs (narrow)

the rule-based inference model by computer program, and to evaluate the effectiveness of the rules designed in this paper. The other is to evaluate the reasoned results through the questions by subject in order to compare the difference between reason results and subject's feeling about landscape in terms of selected human sensibility words.

For the preparation of experiment, hundreds of human sensibility words were gathered for landscape evaluation. From these words, forty words were selected as effective words well presenting the landscape image through the SD evaluation and factor analysis. Subjects groups with fifty university students participated in the experimental study. Fifty-eight samples for the river landscape were prepared and divided into 12 items and 42 categories for design elements as shown in Table 1.

In experiment, subjects check a scaled number for each sample shown in picture in front of them on the SD evaluation sheets. These variables are evaluated by the SD method and analyzed by factor analysis, and then put to the input variables of the Hayashi's regression model. Based on these results, computer simulation was performed in order to show the validity of the proposed model, which is programmed by means of visual basic programming language.

Figure 6 shows the result of Hayashi's quantification theory type I about human sensibility word, 'broad'. In figure 6, the numerical values located in the center present category scores about each category. The left ones and right ones present partial correlation coefficients and range values, respectively. From partial correlation coefficients, it is understandable that riverside road and water surface with high values give people broad image about the river landscape. In other words, in case of designing the river landscape with broad image, it is necessary to consider riverside road and water surface as important factors to give people spacious feeling as a favorite image among river landscapes. Some items such as bridge color, water surface, and embankment have high range values. This means that these items can be also acted as important factors to give 'broad' image.

Figure 7 shows the value of multiple correlation coefficients about some human sensibility words gained from regression analysis. The words having higher value such as 'broad', 'seasonal', 'well arranged', and 'allowable' mean that these words have high relationship with the river landscape presented by sample. It can be said that these words are very adequate to present the relationship between human sensibility about landscape and the components included in landscape design elements. It is also apparent that favorite images for people living in urban are those that broad space, plentiful, and natural aspects. Therefore, it is important to consider that what characteristics are included in the river landscape design samples related with human sensibility words having high value of multiple correlation coefficients.

For the test of effectiveness about the rule based inference model, computer simulation was performed 600 times as following steps :

Step 1 : Five human sensibility words were selected randomly.

Step 2 : Design elements were decided by five rules respectively.

Step 3 : Comparison measures for selected words were derived through the equations (6)-(10).

Step 4 : A rule was selected by equation (11) and final design elements are decided by the rule.

Step 5 : Comparison measures for other words were derived from the same equations.

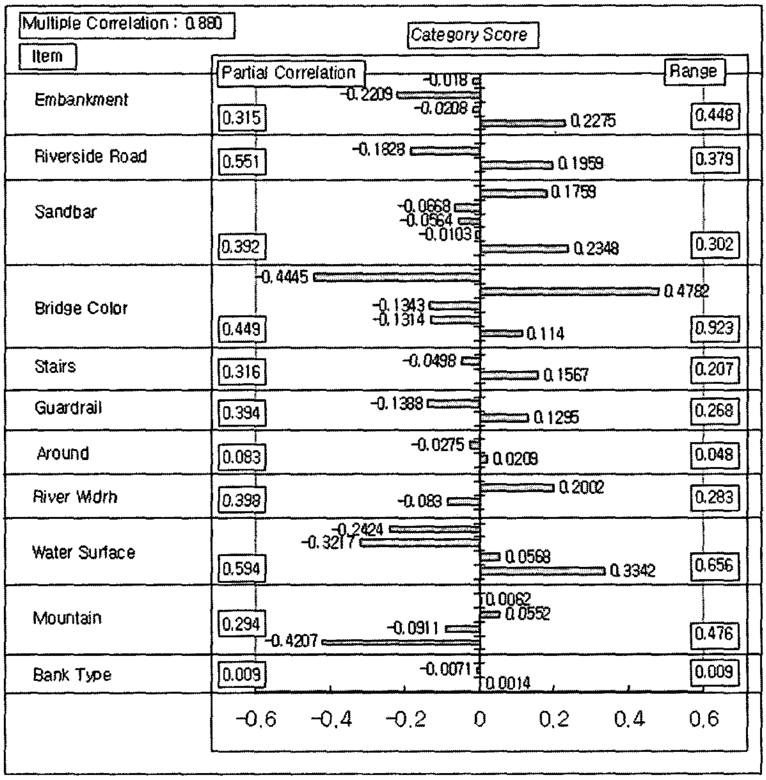


Fig. 6 A result of regression analysis by Haysshi's quantification theory

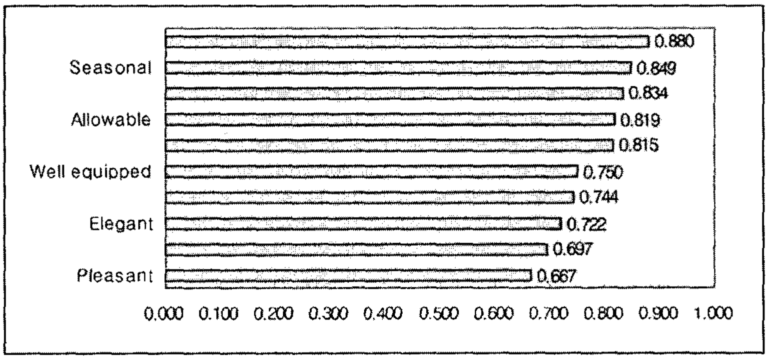


Fig. 7 Human sensibility words and its multiple correlation coefficients related with river landscapes

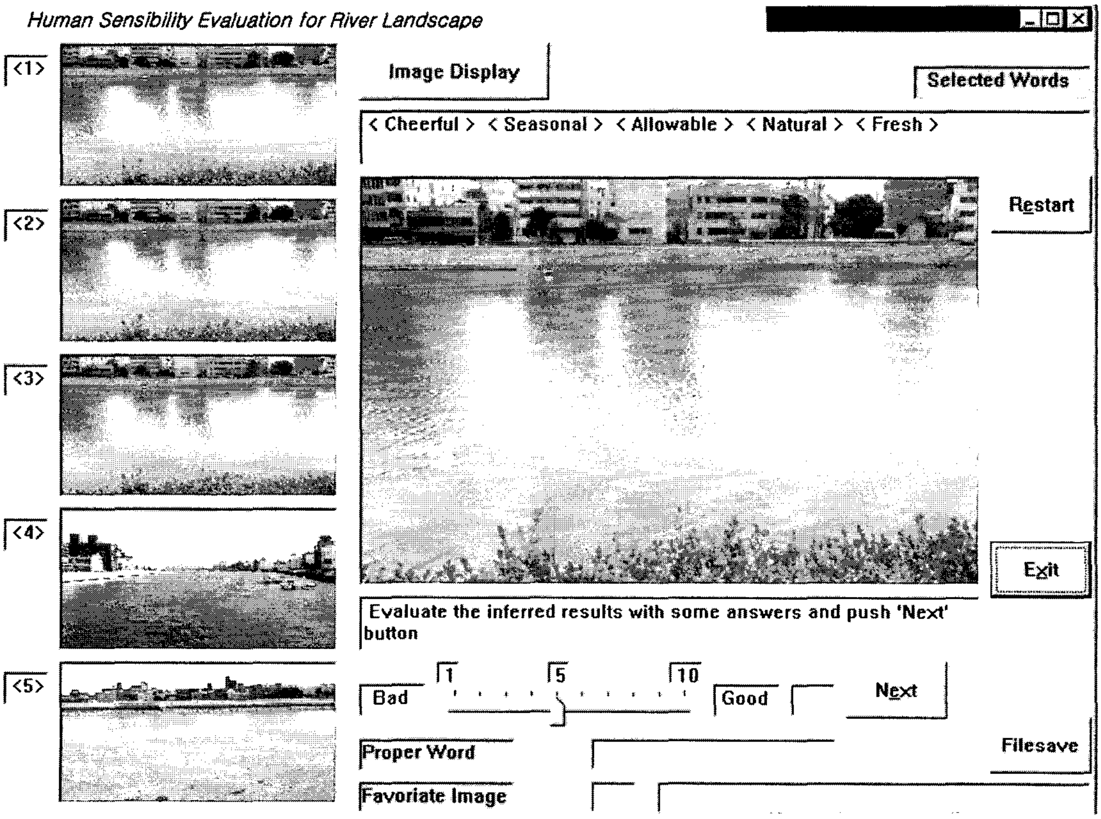
Table 2 shows a simulation result in the case of the river landscape. In this table, items and categories are presented by numbers. $TR(r)$ means comparison measure gained from equations (6)-(10) for each rule. Each rule reasons partially different categories and has different comparison measure. This means that decision variables gained from regression have influence on each rule differently. $TR(r)^*$ was decided as follows and the categories were decided by rule 2 as the final product design elements.

$$
\begin{aligned}
TR(r)^* &= \max\{TR(r)\} \\
&= \max\{0.756, 0.759, 0.664, 0{,}678, 0.724\} \\
&= 0.759
\end{aligned}
$$

Figure 8 shows a reasoned result by inference model. These images are those that have close feeling about human sensibility words, 'allowable', 'natural', 'broad', 'beautiful', and 'clear'. The image positioned in center presents the closest image for selected words reasoned by rule 5, which means that it has the highest reliability

Table 2 An example of the simulation result about selected human sensibility words

Rules/Items	1	2	3	4	5	6	7	8	9	10	11	12	TR(r)
Rule 1-TR(1)	2	1	5	5	5	2	1	2	1	2	2	1	0.756
Rule 2-TR(2)	2	2	5	5	4	2	3	3	2	2	2	2	0.759
Rule 3-TR(3)	2	2	5	5	4	2	3	2	2	2	2	2	0.664
Rule 4-TR(4)	2	2	5	5	4	2	3	2	1	4	1	2	0.687
Rule 5-TR(5)	2	1	5	5	5	2	1	2	1	2	1	2	0.724
TR(r)*=TR(2)	2	2	5	5	4	2	3	3	2	2	2	2	0.759*



< Cheerful > < Seasonal > < Allowable > < Natural > < Fresh >

Evaluate the inferred results with some answers and push 'Next' button

Fig. 8 An example of the evaluation for selected words

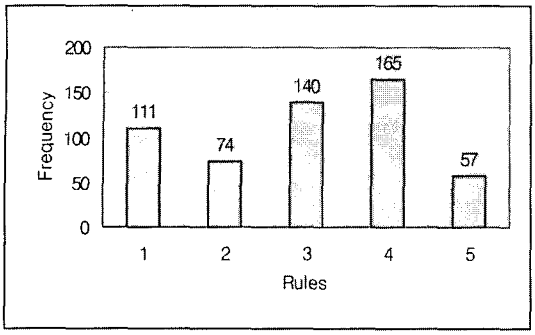


Fig. 9 The selected frequencies of the rules

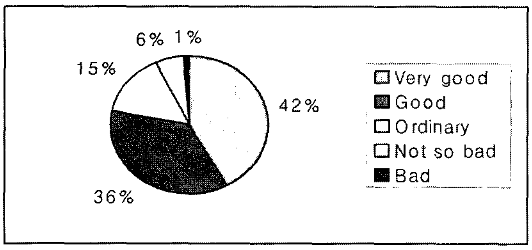


Fig. 10 The evaluation between reasoned results and subject feeling about the river landscape

among the rules.

Figure 9 shows the results of simulation, in which the frequencies of rule 4 are greater than that of any other rules in evaluation of the river landscape. This means that there are many cases having rule 4 as the more effective rule than any other rules. But, there are also cases when rule 1 is more effective or rule 4 is more effective than that of any other rules. In this viewpoint, rule-based inference model can be used effectively for inference mechanism in the HSE.

Figure 10 shows the comparison between the reasoned results by inference rules and the feeling of subjects about landscape. It shows that subjects agree with the reasoned results compared to his or her thought. From this fact, it can be said that the inference model for river landscape evaluation has validity, and that it is applicable to another landscape evaluation or residential environments in addition to product design evaluation.

Finally, the validity of the inference model was tested by means of comparing the difference of comparison measures between selected words and other words. Table 3 shows the results. Two values on each row in left column "Average" mean the average values of comparison measures for selected words and other words with respect to 600 trials in simulation.

Table 3 The results of t-test for the difference

Rule	Average	t-test
Rule 1	0.70, 0.62	12.314
Rule 2	0.74, 0.63	27.131
Rule 3	0.72, 0.60	24.368
Rule 4	0.71, 0.64	16.816
Rule 5	0.73, 0.65	12.237

Values in right column are taken as t statistics for the test of the difference between two average values. It can be said that there are differences between the values by test results such as $12.314 > 2.576$ (t, 600, 0.01). This table shows that the rule-based inference model proposed in this paper has statistical validity.

5. Conclusions and Future Works

In this paper, we proposed the new rule-based inference model with five rules and two inference approaches. On each rule, forward inference reasoned product design elements and backward inference evaluated the result by comparison measurement.

The effectiveness and validity of this model were investigated by computer simulation of the landscape evaluation. Some important points about the inference model were demonstrated by the following. First, by applying various rules, design elements could be reasoned with the same variety for the whole aspects of the product design elements. Second, the most effective rule was selected by backward inference with comparison measures. Finally, discrimination between selected words and the other words could be extracted by statistical test on the comparison measurement.

HSE is a computer-based technique. Therefore, our further research is focused on the development of a more reliable model in which the relationship between human sensibility and design elements will be reasoned out more precisely and much higher reliability can be guaranteed by introducing various kinds of mathematical theories.

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