Artificial Neural Networks for Consumer Oriented Design – A Case of the Best Combination on Product Form Design

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Abstract.

This paper presents a consumer oriented approach, using a grey relational analysis (GRA), neural networks (NNs), and a tabu search (TS) algorithm, to determining the best combination of product form design. The GRA model is used to identify the most influential elements of product form. The NN model is used in conjunction with the GRA model, in order to predict and suggest the best form design combination. The TS is applied to accelerate the search speed for the best global solution. The consumer oriented approach provides useful insights to help product designers work out the best combination of product form design for matching the given product image.

Keywords: Neural Networks; Grey Relational Analysis; Tabu Search; Consumer Oriented; Product form design

1 Introduction

Whether consumers choose a product, depends largely on their perception of the product image [1]. Based on the relationship between the product form and the product image
perceived by consumers, design support models [6] and consumer oriented technologies [9] have been developed as “translating technology of a consumer’s feeling and image of a product into design elements”. They help designers realize consumers’ perception to design product form for the given product image.

In this paper, we present a consumer oriented technology as a hybrid approach, using the grey relational analysis (GRA) [3], the neural networks (NNs) [10], and the tabu search (TS) [4] algorithm. The hybrid approach can be used to help product designers determine the best combination of product form design for achieving the desirable product image. In other words, if needed, the hybrid approach help product designers focus on the desirable product image, and the model will work out the best combination of the product form elements for it.

2 Methodology

In this section, we first present a brief outline of the hybrid approach, including the grey relational analysis (GRA), the neural networks (NNs), and the tabu search (TS), as shown in Fig.1. The GRA model is used to examine the relationship between product form elements and product image, thus identifying the most influential elements of product form for a given set of product images. The NN model is used in conjunction with the GRA model, in order to predict and suggest the best form design combination. Based on the notion, the product design is known to be a hard combinational optimization problem, in particular, the product form and the product image. Hence, the TS is applied to accelerate the search speed for the best form design combination.
2.1 Grey relational analysis (GRA)

The grey relational analysis had introduced by Deng in 1982 [3], and successfully used in any amount of fields [3, 13]. The GRA is a part of the grey system theory, including grey generating, grey relational analysis, grey prediction, grey decision making, and grey control [3]. The grey relational analysis is used to determine the relationship between two series of stochastic data in a grey system. One is called “reference series, \( x_0 \in X \)”, and the other is called “compared series, \( x_i \in X \) (\( i \neq 0 \))”. The \( X = \{ x_\sigma | \sigma = 0, 1, ..., n \} \) is a given grey relational element set. For reference series \( x_0 \) and compared series \( x_i \), the function is used to calculate relational elements of two series at a certain time point. The grey relational grade
between two series at a time point k is called grey relational coefficient \( r(x_0(k), x_i(k)) \):

\[
r(x_0(k), x_i(k)) = \frac{\min_{i} \min_{k} \left| y_i(k) - y_o(k) \right| + \xi \max_{i} \max_{k} \left| y_i(k) - y_o(k) \right|}{\left| y_i(k) - y_o(k) \right| + \xi \max_{i} \max_{k} \left| y_i(k) - y_o(k) \right|}
\]

(1)

where \( \xi \in [0,1] \) is the distinguishing coefficient to control resolution scale, typically taken as 0.5. With relational elements, we can calculate the grey relational grade of each compared series \( x_i \) to reference series \( x_o \) at all time points,

\[
r(x_0, x_i) = \frac{1}{n} \sum_{k=1}^{n} r \left( x_0(k), x_i(k) \right)
\]

(2)

When \( x_i \) equals \( x_o \), the coefficient of grey relation is \( r(x_0(k), x_i(k)) = 1 \) at a time point k. This shows that \( x_i \) is highly related to \( x_o \). If \( r(x_0, x_i) > r(x_0, x_j) \), then the element \( x_i \) is closer to the reference element \( x_o \) than the element \( x_j \).

2.2 Neural networks (NNs)

The neural networks (NNs) are non-linear models and are widely used to examine the complex relationship between input variables and output variables [10]. The NNs are well suited to formulate the product design process for matching the product form (the input) to the consumer’s perception of product image (the output), which is often a black box and cannot be precisely described. Due to their effective learning ability, NNs have been applied successfully in a wide range of fields, using various learning algorithms [7, 12]. In this paper, we use the multilayered feedforward NNs trained with the backpropagation learning algorithm, as it is an effective and the most popular supervised learning algorithm [10].
2.3 Tabu search (TS)

The tabu search (TS) is a metaheuristic originally developed by Glover, which has been successfully applied to a variety of combinatorial optimization problems [4, 5]. The TS algorithm also uses tabu list to force the search for expanding into new directions instead of local minima. Applied to the optimization problems, TS starts at some initial solution and then moves to a neighboring solution. A neighboring solution is generated by a set of admissible moves. The TS uses the Tabu list that prohibits the method from moving to solutions that have certain attributes. Therefore, The TS moves to the best solution at each iteration. The most basic concept of TS algorithm comprises as follows [4, 5]: (1) A methodology for generating an initial solution. (2) A mechanism for generating a neighboring solution of the current solution. (3) A function that measures the attractiveness of each neighboring solution. (4) A Tabu list in order to prevent cycling and lead the search to unexplored regions of the solution space. (5) An Aspiration criterion in order to override the Tabu list as there is a better solution than the best obtained so far. (6) Diversification scheme for moving the search to new areas of the solution space to obtain global solution. (7) Stopping criteria for terminating if no improvement is obtained for a predefined number of diversification steps or if the number of steps exceeds the maximum.
3 The procedure of the consumer oriented approach

In this section, we introduce the procedure of the consumer oriented approach, a hybrid approach, to determine the best combination on the product design field. We emphasize the concept description of the hybrid approach. This procedure comprises the following six steps:

(1) Extracting representative experimental samples:

First, we should decide what products are chosen as the object of the experimental study. We should then focus on investigating and categorizing of various products in the consuming market. The experimentalists or subjects separate the chosen experimental product samples into several groups by the product samples’ similarity degree using the Kawakida Jirou (K.J.) method [2]. The method was introduced by Kawakida Jirou in 1953 for classifying ideas, concepts, or objects into several groups [2]. It has been successfully applied to a variety of classification problems. Based on the K.J. results, we build a similarity matrix from the separation result. Subsequently, we apply the multidimensional scaling (MDS) analysis and then perform the cluster analysis or the factor analysis based on the MDS result. We can obtain the cluster tree diagram or the scatter diagram and can extract the representative experimental samples from the diagram.

(2) Morphological analysis of product form elements:

The morphological analysis [6] is used to extract the form elements of the representative experimental product samples (ex. the mobile phones) by surveying product design experts.
In this paper, the product form included not only the outline shapes, but also the product elements. The morphological analysis can involve two primary processes. In the first process, the experts were asked to write down the influential form elements of the experimental product samples individually according to their knowledge and experience. The survey result was separated into two parts, the “form feature” and the “form treatment” [1]. The “form feature” indicated the size and shape of outline components that make up the mobile phones, such as buttons, icons, a screen or a body shell. The “form treatment” described the relationship between the outline components, for example, the equidistance arrangement of the buttons. In the second process, the same experts formed a focus group to discuss and examine the survey result. The similar components or opinions were combined or discarded. The result of the morphological analysis is reported in our prior study [8].

(3) Evaluating product image of experimental samples:

To evaluate the degree to which the experimental samples match a given set of product images, subjects of the expert group are involved in the experimental evaluation. This purpose is conducted to grasp the consumer’s perception or psychological feeling about a new product using the semantic differentials (SD) method [11]. Pairs of image words are often used to describe the consumer’s image of the product in terms of ergonomic and psychological estimation. The procedure of extracting image word pairs includes the following four steps: (1) Collect a large set of image word pairs from magazines and product catalogs. (2) Evaluate collected image word pairs using the SD method. (3) Apply factor analysis and cluster analysis to the result of SD obtained at Step 2. (4) Determine three representative image word pairs based on the analyses performed at Step 3. The evaluation
result collects numerical data about the relationship between the product images and product form elements for applying the hybrid approach analysis.

(4) Experimental analysis of GRA:

The GRA model calculates the grey relational degree between each comparison series \( x_i \) and the reference series \( x_0 \), using (1) and (2). In this paper, the comparison series \( x_i \) (i = 1, 2, … 9) are the product form elements. The reference series \( x_0 \) are the values of product image. The procedure of GRA involves the following seven steps: (1) Represent the original data series. (2) Normalize the data series. (3) Calculate \( \left| x_i(k) - x_0(k) \right| \). (4) Calculate \( \max \{\max \left| x_i(k) - x_0(k) \right|\} \) and \( \min \{\min \left| x_i(k) - x_0(k) \right|\} \). (5) Set the distinguishing coefficient \( \delta = 0.5 \). (6) Calculate the grey relational coefficient of the data series by (1). (7) Calculate the grey relational degree of the data series by (2), and obtain the value of \( r(x_0, x_i) \), as shown in Fig. 2.

![Fig. 2. The result of the grey relational analysis](image)
The result can identify the most influential elements of product form for a given set of product images. The GRA model can be used to simplify the NN model for helping product designers focus on more influential form elements. In our prior study [8], the result implies that excluding less influential form elements from a NN based model, according to the GRA model, may have no impact on the prediction performance.

(5) Experimental analysis of NN model based on the GRA model:

A typical three-layer network consists of an input layer, an output layer, and one hidden layer. In the NN, the learning algorithm has two processes, including the training process and the test process [10]. This paper develops the NN model based on the GRA model, called the GRA-NN model to determine the best combination of product form elements for matching a set of desirable product image. The procedure of GRA-NN model involves the following three steps: (1) Building the GRA-NN model. For all input variables, we use the type value of 1 to indicate that the input variable is characterized by the type of the corresponding form element. If the input variable has no the type characterization, its type value is set to 0. The evaluation average values of the product image are used as the output neuron, ranging between 1 and 7, as specified in the experimental study. The number of neurons of the hidden layer is dependent on the ideal solution of each model, and is different in each case. (2) Training the GRA-NN model. Totally experimental samples are used as the training samples. When the root of mean square (RMS) errors is convergent, the training process is thus completed. (3) Performance evaluation of the GRA-NN model. In order to examine if the GRA-NN model can be applied to new samples, the test samples are used. The new subjects are involved in the test process, using the SD method [11] with a 7-point scale (1-7). We can
calculate the model’s corresponding RMS errors to compare the performance of the model.

(6) **Tabu search for the optimal combination of product form design:**

In applying tabu search to solving a specific problem, neighborhood structure, tabu list, and search strategy are crucial for improving the performance. The prediction image values of the output neurons of the GRA-NN model are inputted to the TS algorithm as the initial solution. The solution space is all combination of design form elements according to the morphological analysis. As a result, a form design database consisting of different combinations of product form elements together with their associated product images can be built. In this paper, a move is the operation of changing the value at a given position to the next possible value, that is, a move changes 0 to 1, and 1 to 0. For example, for the initial solutions of 1101, the neighborhood of a solution is obtained by applying the move to all the positions as follows: 0101, 1001, 1111, and 1100. A candidate list is the part of the neighborhood that is evaluated to determine the solution for the next iteration. In this paper, the complete neighborhood is included in the candidate list. All the solutions of the candidate list are evaluated and the best solution is made the current solution. With aim of choosing good moves, the aspiration criterion requires that the solution is considered better than the current best solution. The stopping criteria for terminating if no improvement is obtained for a specified number of iterations or if the number of steps exceeds the maximum. The TS algorithm can apply for the GRA-NN model to accelerate the search speed for the best product form combination in terms of a set of desired product images.
4 An illustration

The consumer oriented approach provides useful insights in transforming consumer perception into product form design. The product designer can focus on the determination of a desirable product image, and the NN models can help determine what combination of form can best match the desired product image. These design-supporting results provide useful insights in designing a new product for reflecting the images of the product. To illustrate, Fig. 3 shows the optimal combinations of product form for the product image represented by the S-C image, which is the closest among all combinations. Furthermore, the design-supporting results in this paper can be used, in conjunction with computer aid design (CAD) system or virtual reality (VR) technology, to build a 3D model for facilitating and simulating the design process of mobile phones, as shown in Fig. 4.

Fig. 3. The 3D models of the CAD system
5 Conclusion

In this paper, we have presented a new consumer oriented approach, using a grey relational analysis (GRA), neural networks (NNs), and a tabu search (TS) algorithm, for determining the best combination on product form design. The procedure of the consumer oriented approach comprises six major steps. The consumer oriented approach would help the product designers better understand consumers’ perception of product form with respect to the corresponding product images. This paper provides useful insights in designing form elements of a product for matching a set of product images. Although this paper is focused on product form design, the approach can be applied to other products with various design elements.
References


