論 文 の 内 容 の 要 旨

論文題目

Efficient Generative Methods for Assisting Aesthetic Design in Conceptual Stage

（コンセプト段階での意匠設計支援のための効率的なジェネラティブデザイン手法）

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Conceptual design is one of the stages of common design process models in which many solutions are developed in basic forms for a design problem. The solutions are then evaluated and proceeded to the next stages where the selected solutions are detailed and further tested. The aesthetic is an important criterion that needs to be satisfied to differentiate a product from competitors in the market. However, there are often many other criteria such as engineering design constraints, cost and time that elevate the difficulty of developing the aesthetic ideas. In this thesis, there are two approaches considered to be helpful for this problem. The first approach is a human-oriented design method that represents customer feelings about the design aesthetic by a set of design parameters. To do this, a survey method is proposed that monitors the eye movements of the participants to figure out the attractive and more relevant parameters to the given set of goals. The second approach is a generative design method, which provides many design alternatives to explore solution candidates among them. The generative method is implemented by software to lower the required efforts for generating the design samples. Also, the users can define their geometric constraints through the proposed software to narrow down the solutions.

The proposed approach in Chapter 2 uses an adjective-based design method, which translates human perception into design parameters quantitatively to achieve better understanding between designers and clients. In this approach, adjectives are used to describe product designs, which are generated via design parameters in terms of geometry. As a requirement of the concept, relations between hull adjectives (e.g., comfortable and aesthetic) and design parameters (e.g., length and width) are learned via a machine learning algorithm. Nevertheless, the relations cannot be represented by some of the design parameters, although they are in the learning process. This finding shows that the parameters do not affect the adjective choices of the survey participants but add noises to the learning process; therefore, avoiding such parameters beforehand, the reliability of the human-oriented methods' outcomes can be enhanced and samplings can be made efficiently with less number of parameters. However, traditional multiple choice questionnaires are neither reliable nor capable of creating questions to reveal true feelings of people, who do not have a background in design and have difficulty to articulate their aesthetic opinions only by words. Eye tracking is one of the methods to study human behaviors based on attention for more objective and accurate data collection regarding the subjective feelings of the customers. One of the advantages of eye tracking is that the data can be analyzed visually using eye tracking tools such as area of interest (AOI) that encloses an area that will be examined, heat maps that represent attractive regions of the stimuli by a color scale, and gaze plots that display the gaze transitions from one spot to another. Second, it provides quantitative measures such as the locations that the subjects look, the time spent on these locations, and gaze transition counts between specific locations. Therefore, in this thesis, visual evaluations are made using eye tracking technology for screening the parameters based on their attractiveness and establishing relations between the attractive ones and the adjectives to enhance the quality of the relation representations.

Eye tracking aided survey (ETAS) is used to collect gaze data while the survey participants match 54 static images of generated yacht hull designs with ten hull adjectives. Furthermore, a template learning survey is used to figure out how participants observe design parameters to decide on a suitable eye tracking tool to evaluate each parameter. ETAS results are then visually and quantitatively analyzed using the eye tracking tools to get gaze metrics, which are relative time durations and transition probabilities. In the end, based on the gaze metrics, unattractive design parameters are first eliminated and the relationships between the remaining parameters and the adjectives are then analyzed using regression analysis.

The regression models are found using the generalized linear model (GLM) and best-subset selection method. The best-subset method first calculates the residual sum of squares (RSS) for the all possible regression models found by GLM and only top models with minimum RSS are determined. These models are then evaluated according to the Akaike information criteria (a measure of information loss) and $D^2$ (explained data variance ratio) to select the best model for each adjective that is represented with only the relevant parameters. As a result, significant correlations between parameters and the participants' preferences through the gaze data have been found. It is believed that the knowledge of attractive design parameters and their relevance to the objectives are useful as guidance for designers for the efficient and effective aesthetic design process.

In Chapter 3, a sampling approach is proposed for deriving profiles of an existing product design using profile similarities and primitive shapes, such as circles, triangles, and ellipses, as constraints. A common approach for a designer is to generate or collect sketches to create a design space. The design space can be explored to retrieve the samples directly based on requirements or crossing over them to obtain new design variations. In this stage, the proposed method can be used to derive many samples from a design image to work with. First, the user clicks on the image to define each design feature as a cubic Bézier curve segment. The primitive shapes are then constructed for each segment and used as constraints, such that adjacent triangles are not allowed to be flipped onto each other to prevent loop and cusp at the segments, sides of internal points respect to the circle diameter is used to prevent inflections, and control points are not allowed to cross the ellipse boundary to limit their excessive modifications. Besides, the method allows partial modifications, in which users can select a specific region to modify while the rest of the shape maintains the original appearance and functionality of the exemplary design. Moreover, the design similarities are computed using the triangles based on their anisotropy ratios, which are measures of the deformation between corresponding triangles and which are used to ensure that they are highly related samples in the example design. Modified Hausdorff distances are also computed between the control points of the samples. There is diversity provided that these distances are large enough. Using the similarity measures, a designer can derive samples sticking to their initial idea to explore its better version or more creative results that they could not imagine on their own. Finally, a chain sampling algorithm that fulfills the constraints and similarity requirements is introduced. The algorithm is also executed several times synchronously via parallel programming to create a larger sample set and a user-specified number of distinct samples is retrieved from this set minimizing the Audze-Eglais potential energy.

The proposed generative method in Chapter 3 is implemented by a software introduced in Chapter 4, which presents optional features, alternative sampling methods and a sample management system through several interfaces. Since the software automatizes most of the steps for the users, even inexperienced users without needing any programming skill can vary shapes defined using a set of points in a matter of seconds, and experienced users can even focus on specific shape features weighting them without dealing any constraint or rule definition requirements. There is a design system interface in which the profile curves are defined using control points imported from text files or provided by mouse clicks over a design image. Besides, it supports profile definitions up to three views of an object, which is then going to be converted into 3D by either sweep or network surface method.

The software includes a tuning interface in which test samples created using Latin hypercube sampling (LHS) method are used to find optimum values for sampling settings such as maximum and minimum modification amounts for the profile curve and thresholds that control similarity and diversity in generated samples. The fan polygons and the ellipses are also visualized in this interface so that users can observe the constraining failures of the test samples while the settings are tuned. Furthermore, it is possible to import a design table to create samples to be used as test samples or for a controlled experiment like needed in the human-oriented design methods explained in Chapter 2.

A sampling interface is utilized to generate and visualize samples using different methods. First, users can derive samples from a single exemplary design using the chain sampling algorithm. The chain algorithm has the potential to be used with different strategies like parallel sampling explained earlier. As another strategy, the chain algorithm is executed several times to be one after another, but each one uses a random or user-selected sample from the previous chain's output as an exemplar to generate a new sample set. Such an algorithm can extend the sampling region to explore more creative samples. The test samples created by the default LHS method or a design table can also be displayed in this interface. The designs here are shown by rows and columns with intervals controlled via sliders. Setting the intervals as "0" the samples can be overlapped at a fixed point to observe the variation of the samplings. Finally, all the samples can be exported appropriately to be converted in 3D models using any external CAD software, which is preferred as Rhino/Grasshopper for this thesis.

A user evaluation interface is also proposed, which creates samples using the chain algorithm and immediately displays to the users. There are radio buttons under each of the design to collect and record user responses as Likert-type scores or like/dislike options depending on the user choice. The samples are generated as long as the user hits the update button and the responses are kept recorded. The high scored samples are stored and visualized in the sampling interface, and all samples with the responses can be exported to analyze using external statistical software. Moreover, the users can assign weights for the modification of each control point to guide the sampling process.

Finally, a sample management interface is offered in which a formula can be created by either the similarity measures or geometric constraints defined by users using functions such as horizontal, vertical and Euclidean distances between points; and width, height, volume and area of the shape. The sample management starts with clustering the samples using the K-means method and each cluster is then organized individually according to the defined formula. The users can set a range with desired maximum and minimum values to filter out the samples whose formula results are out of the range. The samples can also be analyzed with a graph of one formula versus another. Besides, the interface consists of several areas with various purposes such as generating new samples from a selected sample, editing sample and searching similar samples to this edited sample, exporting the selected samples to be converted into 3D in Rhino simultaneously, and pairwise comparison of the selected samples based on a formula.

To sum up, two approaches are studied to increase the efficiency of generating aesthetic ideas. The first approach aims to identify important design parameters for specific aesthetic objectives based on customer feelings so that new designs can be generated with fewer parameters that have direct influences on the target aesthetic objectives. The second approach implemented by a software is for generating many design samples with as minimum as possible effort, time and experience requirements for various profile curves. Finally, problem-specific geometric constraints can be utilized through the sample management system to filter out undesired solutions from the generated samples.