Title:
Study of Aesthetic Curve Design Method Using Impression Word-based Dialogue AI and GAN

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Introduction:

The body shapes of automobiles and home appliances need to be designed to be attractive to people, and the shapes are evaluated based on the lines of curvature, the reflection of the scenery, and the reflection of highlight lines[1,8]. Sone and Chiyokura proposed an aesthetic surface design method using fourth-order blended NURBS boundary Gregory patches with highlight curves as an evaluation index [18]. In addition, Higashi et al. proposed a method to design surfaces formed by the locus that is modified according to a criterion of the highlight lines by defining an evolute surface [9].

In recent years, research into fine-tuned cloth (FTC) has progressed in mathematics [16]. And CREST-ED3GE: Evolving Design and Discrete Differential Geometry project [2] focuses on "the geometry of discrete surfaces with developable surfaces as geometric elements and their discrete variational principles," and is developing a "theory of aesthetic shapes" as well as an innovative design software platform.

The clothoid curve is considered to be one of the most beautiful curves, and its curvature is proportional or inversely proportional to the length of the curve. Taking into account the logarithmic distribution of curvature, a generalized formula is the fine-tuned clothoid (FTC) curve [19]. Therefore, in order to set design guidelines for shapes, Kobayashi et al. developed an aesthetic design support method using “sensitivity” as a keyword and applied it to product development [11]. Harada has also investigated the relationship between the logarithmic distribution of curvature and the visual language used to express design concepts, and has investigated the relationship between human sensibility and shape when designing shapes [6, 7].

With the recent development of optimization and artificial intelligence, research on automatic or interactive shape design systems has progressed. One of these is the use of genetic algorithms [10]. Cohen studied shape optimization methods using NURBS curves and GA optimization, with parametrization of the material boundaries and optimizing those boundaries to define shapes [3]. Using neural networks and genetic algorithms to explore the optimal aesthetic design for chairs. Kobayashi et al. define Optimal design parameters that minimize both the variance of all customers’ utility that are explored by using a multi-objective genetic algorithm and design products that keep a low effect of the variation in customer kansei.[13].

A generative adversarial network (GAN) [5] consists of a generator and a discriminator, where the discriminator judges the veracity of the data generated by the generator and optimizes the design. Using this method, it is possible to generate new images, and MIT has applied GANs to airplane design [17]. Su et al. use StyleGAN3 and a stable diffusion model to generate creative images of hair dryers and improve the quality of the images[19]. There is also research on convolutional neural networks. Zhang et al. used a particle swarm optimization convolutional neural network (PSO-CNN) for 3D reconstruction and rendering[15]. Gai et al. are using a graph convolutional neural network (GCN) model to develop a creative advertising design system that can accurately capture users' interests and behavioral habits [4]. In this way, much of the research into neural networks focuses on image generation.

Research similar to this study, Kobayasi et al. propose a new aesthetic design synthesis method [12] by using SD method to evaluate existing products, extracting decision rules that describe the relationship between user preferences and impressions and aesthetic elements using rough set theory, grouping customers based on the similarity of the extracted rules, and combining the decision rules extracted for each group. However, it can be difficult to create a design with diverse customer decision rules.

In this study, in order to design curves, which are the basis of shapes, based on sensibility, we train a GAN to learn the relationship between the visual language proposed by Harada and shapes expressed with FTC (Fine-Tuned Clothoid) curves. We then train an LLM to learn the relationship between the characteristic shape and the natural language, and develop a system that uses a GAN to predict curve shapes from a language sentence proposed by a designer through dialogue with the LLM (ChatGPT). In this study, we report on the system configuration, learning method, and evaluation results from subject tests.

Design system development:

In this research, we aim to develop a system that uses a designer's design vocabulary to efficiently design cross-sectional curved surface shapes, which primarily determine the characteristics of a shape, in 3D curved surface design. The system configuration is shown in Figure 1. The GAN is pre-trained with the relationship between vocabulary and shapes for each design shape classification. Then, the user inputs the design intent via LLM, and the GAN uses the pre-trained data to create an appropriate curve shape and presents it to the user..

First, we defined the relationship between design vocabulary and shapes. Table 1 shows curves with typical characteristics and the characteristic vocabulary that represents them. There are 18 categories, and each category contains a collection of similar curves.

Figure 2 shows the shape curves corresponding to the classified features. These curves are generated using FTC curve is express as [14]:

$$FTC(t, C_0, C_1, C_2, \alpha) = \frac{C_0}{2(C_1+i\alpha)} e^{iC_2} e^{(C_2+i\alpha)t^2} \tag{1}$$

Here, α is curvature related constant, C_0,C_1,C_2 are shape related constant. t represents the axis of time or space.

For curves with one classification, 40-50 example shapes were created and trained on ReACGAN (Rebooting ACGAN: Auxiliary Classifier GANs) using the classification and feature vocabulary. For training, four GPUs (RTX-A4500) were used, and the Tensor Parallelism algorithm was used to utilize the four GPUs for training. In addition, the Mixed Precision Training algorithm was used to improve large-scale learning and computation speed.

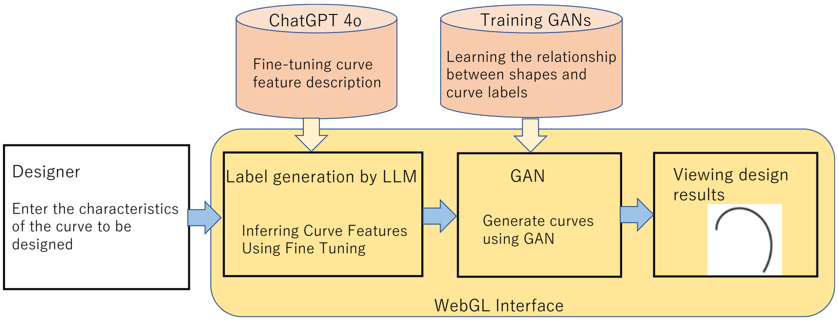

Fig. 1: The system configuration of the curve design system.

Type.	Curve Classification	Curve Characteristics word
1	Stable curve, Shaped for high speed, Fast speed and stretchy shape, Fast speed, little change and gentle shape	stable, massive, speedy, run through, high speed, stretchy,
2	The overall curvature is small with little change in shape, Shape with small curvature, small change, and high speed, A shape with low overall curvature and little change at a constant and fast speed	small deviation, small curvature, speedy, high speed
3	Curves that evoke the image of vastness, Fast speed and small shape change, Fast speed, little speed change and stretchy shape	flat image, large image, small curvature deviation, small curvature,
4	Curves that evoke the image of vastness, Fast speed and small shape change, Fast speed, little speed change and stretchy shape	vast expanse, Widen, High speed, small curvature deviation, small speed deviation,
5	Shaped for high speed, Fast speed with little change and flat shape, Faster speed and less rounded shape	High speed, run through, small speed deviation, flat, Less rounded
6	Curves that evoke elegance, Dynamic curves	Grace, Elegant image, Dynamic, uplifting,
7	The curve has a large overall curvature, and is reminiscent of a shape that gradually increases in speed from the tip, A curve that represents a shape that accelerates at a constant rate from a point of large curvature, Curves that evoke a rounded and dynamic shape	Large curvature, Gradually increasing speed, Accelerate at a constant velocity rate, large curvature at start area, rounded, dynamic
8	Curves that evoke an organic image, Curves with a powerful image, Curves that imagines a curve with a large to medium curvature,	Organic image, powerful, Bull image, middle is flat, stable, gradual incline,

Tab. 1: Classification of typical curve shapes and the characteristic vocabulary.

(1) Type–1 shapes

Fig. 2: Example of the relationship between characteristic curve shape and classification.

Evaluation of design system:

The developed system was evaluated by a total of 15 people from Tokyo Polytechnic University, including three from the Faculty of Arts and 12 from the Faculty of Engineering. The questionnaire was divided into three categories: "Evaluation of suitability of the curve and achievement of purpose," "Evaluation of the shape and naturalness of the curve," and "Evaluation of the beauty and impression of the curve," and was rated on a five-point scale.

Figure 3 shows the results of the survey on "Evaluation of suitability of curves and achievement of purpose." Evaluation was divided into three categories: "As intended," "Appropriate for vocabulary," and "Highly practical." With regard to the design intent, many people answered "Probably so," suggesting that many people are not accustomed to evaluating curves based on their curve characteristics, but that the design was intended to some extent.

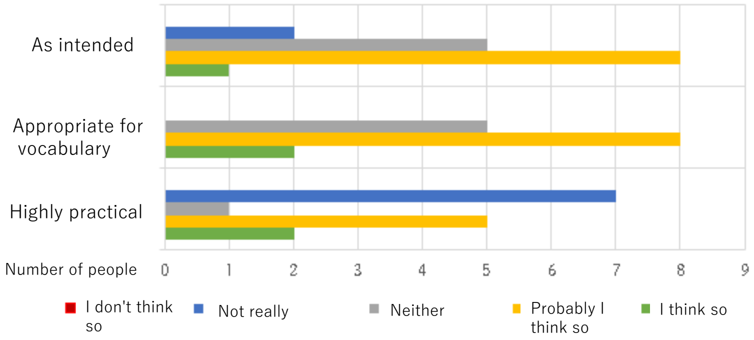

Fig. 3: System evaluation results 1.

Conclusions:
In this study, we aimed to design cross-sectional curves, which are the basis of 3D free-form surface shapes, based on aesthetic sensitivity. We expanded the visual aesthetic language proposed by Harada, learned the relationship between the vocabulary, curve shape, and FTC curves is learned using a GAN. Users express features in natural language and input them to the system using an interactive LLM, and the GAN infers the shape. As a result, we believe that by utilizing this system, we have achieved the first step in generating curve shapes that are close to the user's intentions.
We plan to continue improving the algorithm so that it can generate curves that are closer to the intended result.

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