

## Research Article

# Parametric Design and Kansei Engineering in Goblet Styling Design

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In this study, we developed a computer-aided product design method for goblet styling design based on two methods. The first was parametric design derived from an adjustable cam mechanism, which was used for shape generation, and the second was Kansei engineering, which was used for shape evaluation. In the shape generation method, motion curves from an adjustable cam were used. Designers can collect feature point data from existing products to define the boundary conditions of adjustable cam motion equations; furthermore, adjustable motion curves allow parametric design. Through adjusting a single parameter, motion curves were changed to be used as projective curves for the styling design of goblets. Then, a coordinate transformation method was applied to support the three-dimensional styling design of goblets. In the shape evaluation method, some goblet stylings were regularly selected to determine adjective degrees by production design experts. Adjective degrees for goblets that had not been selected were determined through interpolation. Market demand was defined as the preference of customers for specific adjective degrees for goblets.

## 1. Introduction

Cam mechanism is used to transmit a desired motion to another mechanical element through direct surface contact [1, 2]. A small error on a cam profile can cause a large response of a follower. Thus, the cam profile is not adjusted to maintain the desired motion. Several traditional methods, including the envelope [1, 2], conjugate surface method [3], polar method [4], relative velocity method [5], relative acceleration method [6], and approximate analytical method [7], are available to design the cam profile without adjustment. These traditional methods focus on the synthesis of the cam profile without adjustment.

In a special case, the cam profile can be adjusted to generate various strokes of a follower. For example, the knockout mechanism of the bolt former can be adjusted to achieve various knockout strokes to knockout bolts of different lengths [8–11]. An adjustable cam mechanism in an engine can achieve different timings to adapt to the different

intake and exhaust stroke volume of gas that matches the high-speed and low-speed rotation of the engine. The aforementioned studies have only proposed the design concept of an adjustable cam mechanism without specifying design methods.

Several approaches have been proposed for designing the adjustable mechanism. Chang [12] proposed the synthesis techniques of adjustable four-bar linkages for tracing variable arcs with prescribed tangential velocities. Zhou and Ting [13] adjusted the position of the slider guider of slider-crank linkages for multiphase motion generation. Wu and Chen [14] presented an adjustable four-bar linkage with an adjustable length link to synthesize linkage through more precision points. Ahmad and Waldron [15] used an adjustable fixed pivot of the driven link to design adjustable four-bar linkages for motion generation. Krishnamoorthy and Kothadiya [16] presented a method to synthesize a four-bar linkage with an adjustable fixed pivot to obtain two intersecting straight lines. Wang and Sodhi [17] adjusted the

moving pivot position of a four-bar linkage to generate multiphase motion. Zhou [18] adjusted the length of the coupler or the driven link for precise function generation. Pennock and Israr [19] presented an adjustable six-bar linkage with an adjustable input crank to synthesize the extreme positions of the output link and coupler link. Sedano et al. [20] presented a hybrid optimization approach for the design of linkages. The method is applied to the dimensional synthesis of the mechanism, and the merits of both stochastic and deterministic optimization are combined. Wilhelm and Ven [21, 22] presented the synthesis, analysis, and experimental validation of a variable displacement six-bar crank-rocker-slider mechanism that uses a conventional variable pump. However, all the aforementioned studies have focused on methods for designing an adjustable linkage mechanism. In 2005, Hwang and Yu [23] proposed a method for designing an adjustable cam mechanism to design a cam profile with adjustment. For the cam profile with a polynomial segment, in addition to specified boundary conditions, one parameter was used as a design variable of an optimization design. In this study, we applied the design method of the adjustable cam mechanism for computer-aided goblet styling. Feature point data from existing goblets were collected to define the boundary conditions of adjustable cam motion equations and thereby obtaining the curve of the existing goblet. Subsequently, one parameter was adjusted to generate various goblet shapes.

Parametric design is crucial and often applied to various design areas, such as building design and product design [24–31]. By incorporating computer-aided design, parametric design can facilitate generating design ideas quickly. Zhan [32] presented an automobile styling design system, which uses the characteristic of cam motion equations in mechanisms, to help industrial designers in concept development stages. One of the distinguish features of this study is that the contour of an automobile can be represented by the cam motion equations using small amount of control points. This study uses two cam motion curves to define the coordinates of the longitudinal section line and the cross section line of the car and then synthesize them into a 3D car shape. Łukaszewicz [33] proposed the multibody approach to design in-part environment in parametric computer-aided (CAD) systems. Different types of multibody methods and tools that use this approach are discussed. Bodein et al. [34] proposed a general strategy for using the advantages of parametric CAD in the automotive industry in the form of a roadmap. The main stages of the roadmap were illustrated through industrial use cases. Camba et al. [35] presented an analysis of formal CAD modeling strategies and best practices for history-based parametric design: Delphi's horizontal modeling, explicit reference modeling, and resilient modeling. Oxman [36] examines the uniqueness of seminal parametric design concepts and their impact on models of parametric design thinking. Łukaszewicz et al. [37] presented the process of designing a technological line for transporting and packaging vegetables by using a parametric 3D CAD system. Lobaccaro et al. [38] presented parametric design to minimize embodied greenhouse gas emissions and operational

energy in a zero emission building in Oslo, Norway. In addition, a generative design method was designed based on parameters. It is a type of styling method that imitates nature and uses nonlinear algorithms to create infinite changes [39, 40].

In 1986, Yamamoto proposed Kansei engineering for designing the exterior of automobiles; other relevant studies have applied Kansei engineering to the design of various products [41–44]. Jindo and Hirasago applied Kansei engineering and quantification theory type I to car interior design to determine relationships between Kansei images and the styles of car dashboards, speed pointers, and scales to determine the safest combination [45]. Horiguchi and Suetomi applied Kansei engineering to the design of car-driving systems using a driving simulator [41]. Lai et al. discussed the association between imported and domestically manufactured cars with respect to style and affective elements; the researchers used Kansei engineering to explore correspondence between a car's viewing angle and its style and affective elements [46]. Kansei engineering was used to support construction machinery design as a scientific method of incorporating human sensibilities into the applied design [47]. Guo et al. presented the integration of KE models and used the genetic algorithm to search for a mini digital camera design scheme [48]. Hsu proposed a frame based on the intelligent computer-aided industrial design system, which used a goblet as an example. Referring to previous research, Hsu proposed 32 adjectives and allowed 30 participants to select those that best described goblet styling. The top five adjectives with the highest statistical values were as follows: steady, streamlined, emotional, elegant, and gentle [49]. Chen explored the relationship between goblet styling and adjectives based on the theory of Kansei engineering. Through an extensive collection of goblet images and adjectives, six representative adjectives were screened using the KJ method: trustworthy, crisp, valuable, novel, warm, and leisurely [50].

The aforementioned studies have focused on designed products, and experts have determined adjective degrees that described products. Other than the aforementioned method, in this study, the adjective degrees of targeted products that are yet to be designed were estimated using the interpolation method. In the present study, Kansei engineering was used to design a goblet. The goblet designed using the design parameter was then scored by experts using Kansei engineering criteria, and adjectives used to describe goblet's appearance were defined accordingly. This enabled producing goblets based on customer preferences.

## 2. Parametric Design

In this study, adjustable cam motion equations were applied to develop a computer-aided product design method for designing goblets. When the adjustable cam was adjusted with the adjustment screw, the cam profile could be adjusted around the adjustment axis (Figure 1). The cam profile rotated clockwise at angle  $\theta$  around the adjustment axis. The cam motion curve changed because the relative position between the cam profile and the roller changed. By adjusting

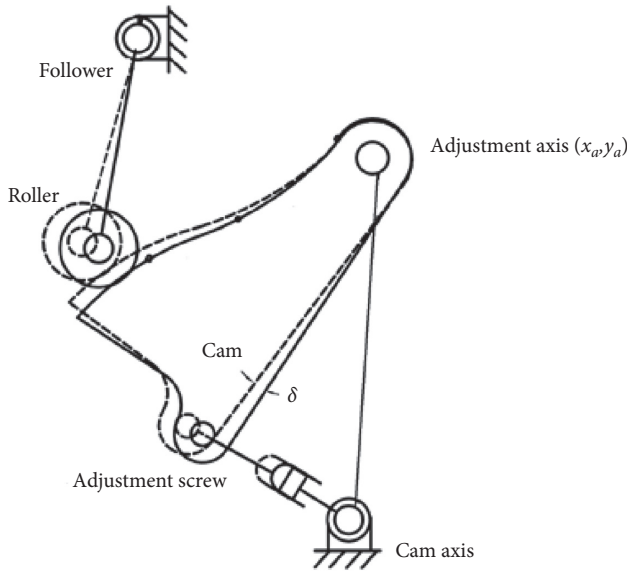


FIGURE 1: Adjustable cam.

a single parameter  $\delta$  to change adjustable cam motion curves, projective curves were generated for producing various 3D goblet shapes. The design procedure is as follows.

**2.1. Determining Cam Motion Equations.** The most common types of cam motion include simple harmonic, cycloidal, elliptical, and polynomial motions. Because the goblet projective curve requires 5 feature points to control, fourth-degree polynomial motion curves were used in this study to design goblets. The fourth-degree polynomial curve of the follower motion is expressed as follows:

$$\phi(\theta) = C_0 + C_1\theta + C_2\theta^2 + C_3\theta^3 + C_4\theta^4, \quad (1)$$

where  $\phi$  is the angular displacement of the follower and  $\theta$  is the angular displacement of the cam in the period corresponding to the fourth-degree polynomial curve, which has derivatives as follows:

$$\phi'(\theta) = \omega(C_1 + 2C_2\theta + 3C_3\theta^2 + 4C_4\theta^3), \quad (2)$$

where  $\omega$  is the angular velocity of the cam.

According to the goblet style, two feature points controlled the front end of the goblet-shaped projective curve, two feature points controlled its back end, and one feature point controlled its midpoint. Straight lines were connected to the beginning and end of the fourth-degree polynomial curve to form a goblet-shaped projective curve. Equation (2) was zero at the initial point and terminal point, which smoothed the connection between the straight lines and the fourth-degree polynomial curve. The five boundary conditions required are specified as follows (Figure 2):

At the initial point of the period:  $\phi(0) = 0, \phi'(0) = 0$

At the middle point of the period:  $\phi(0.5\theta_t) = \phi_m$

At the terminal point of the period:  $\phi(\theta_t) = \phi_t, \phi'(\theta_t) = 0$

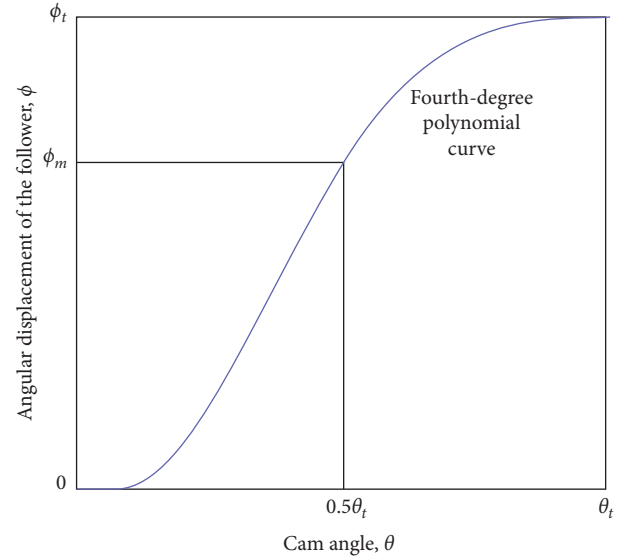


FIGURE 2: Angular displacement of the follower corresponding to the fourth-degree polynomial curve.

$\theta_t$  is the total angular displacement of the cam in the period corresponding to the fourth-degree polynomial curve,  $\phi_m$  represents the angular displacement of the follower to be specified when  $\theta = 0.5\theta_t$ , and  $\phi_t$  represents the angular displacement of the follower to be specified when  $\theta = \theta_t$ .

Substituting the aforementioned conditions into (1) and (2) and solving the simultaneous equations yield

$$\begin{aligned} \phi(\theta) = & (16\phi_m - 5\phi_t)\left(\frac{\theta}{\theta_t}\right)^2 + (14\phi_t - 32\phi_m)\left(\frac{\theta}{\theta_t}\right)^3 \\ & + (16\phi_m - 8\phi_t)\left(\frac{\theta}{\theta_t}\right)^4. \end{aligned} \quad (3)$$

**2.2. Synthesizing the Cam Profile.** In this study, disk cams were categorized according to various types of followers and kinematics: disk cam and translating flat-faced follower, disk cam and translating roller follower, disk cam and rotating flat-faced follower, and disk cam and rotating roller follower. We then raise the disk cam and rotating roller follower as an example to discuss the motion curve equation and the cam profile of the adjustable cam mechanism.

In addition to related parameters, such as the roller radius, distance between the center of the cam axis and the center of the follower pivot, radius of the cam base circle, start angle of the follower, length of the follower arm, included angle between the line (from the cam axis to the follower pivot) and the  $x$ -axis, the angular displacement of the cam should be determined. We can then acquire the equation for the cam profile. The cam profile and the central coordinate of the roller corresponding to the fourth-degree polynomial curve are then synthesized by the inverse method and envelope theory [1, 2]:

$$\begin{cases} x = x_{C1} - r_f \left( \frac{dy_{C1}}{d\theta} \right) \left[ \left( \frac{dx_{C1}}{d\theta} \right)^2 + \left( \frac{dy_{C1}}{d\theta} \right)^2 \right]^{-1/2}, \\ y = y_{C1} + r_f \left( \frac{dx_{C1}}{d\theta} \right) \left[ \left( \frac{dx_{C1}}{d\theta} \right)^2 + \left( \frac{dy_{C1}}{d\theta} \right)^2 \right]^{-1/2}. \end{cases} \quad (4)$$

Equations of the related parameters are as follows:

$$\begin{aligned} \frac{dx_{C1}}{d\theta} &= -r_c \sin \theta + r_a \left( 1 - \frac{d\phi}{d\theta} \right) \sin(\theta - \beta - \phi), \\ \frac{dy_{C1}}{d\theta} &= r_c \cos \theta - r_a \left( 1 - \frac{d\phi}{d\theta} \right) \cos(\theta - \beta - \phi), \\ x_{C1} &= r_c \cos \theta - r_a \cos(\theta - \beta - \phi), \\ y_{C1} &= r_c \sin \theta - r_a \sin(\theta - \beta - \phi), \end{aligned} \quad (5)$$

$$\beta = \cos^{-1} \left( \frac{r_a^2 + r_o^2 - (r_b + r_f)^2}{2r_a r_o} \right),$$

where  $x, y$  are the coordinates of the cam profile,  $x_c, y_c$  are the coordinates of the roller center,  $r_f$  is the roller radius,  $r_b$  is the radius of the cam base circle,  $r_a$  is the length of the follower arm,  $r_o$  is the distance between the center of the cam axis and the center of the follower pivot,  $\beta$  is the start angle of the follower,  $\gamma$  is the included angle between the line (from the cam axis to the follower pivot) and the  $x$ -axis,  $\theta$  is the angular displacement of the cam, and  $\phi$  is the angular displacement of the follower.

**2.3. Adjusting the Cam Profile.** When the adjustable cam was adjusted using the adjustment screw, the cam profile can be adjusted around the adjustment axis to generate various motion curves (Figure 1). The coordinates of the adjusted cam profile and the roller follower were derived using coordinate transformation equations. Point  $(x_{C1}, y_{C1})$  rotates clockwise with angle  $\theta$  around the adjustment axis  $(x_a, y_a)$  from  $(x_{C1}, y_{C1})$  to  $(x_{C2}, y_{C2})$ , and the relationship between  $(x_{C1}, y_{C1})$  and  $(x_{C2}, y_{C2})$  can be represented as follows:

$$\begin{bmatrix} x_{C2} \\ y_{C2} \end{bmatrix} = \begin{bmatrix} x_a + (x_{C1} - x_a) \cos \delta + (y_{C1} - y_a) \sin \delta \\ y_a + (x_a - x_{C1}) \sin \delta + (y_{C1} - y_a) \cos \delta \end{bmatrix}. \quad (6)$$

**2.4. Generate Goblet Styling.** When the central coordinate of the roller is known, we can then work out the motion curve of the follower through geometric analysis [23]. The motion curve is used to design the projective curves for goblet styling. The parameter is depicted in Figure 3.

$$\phi' = \cos^{-1} \left( \frac{r_o^2 + r_a^2 - r_c'^2}{2r_a r_o} \right) - \beta, \quad (7)$$

$$\theta' = \gamma + \alpha - \tan^{-1} \left( \frac{y_{C2}}{x_{C2}} \right). \quad (8)$$

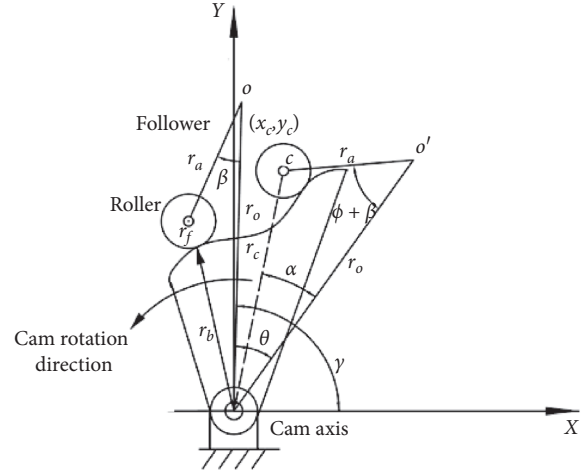


FIGURE 3: Cam inverse method and its parameters.

Equations of the related parameters are as follows:

$$r_c' = \sqrt{x_{C2}^2 + y_{C2}^2}, \quad (9)$$

$$\alpha = \cos^{-1} \left( \frac{r_c'^2 + r_o^2 - r_a^2}{2r_c' r_o} \right), \quad (10)$$

$$\beta = \cos^{-1} \left( \frac{r_a^2 + r_o^2 - (r_b + r_f)^2}{2r_a r_o} \right), \quad (11)$$

where  $r_f, r_b, r_a, r_o, \beta$ , and  $\gamma$  are defined as before.  $x_c, y_c$  are adjusted coordinates of the roller center.  $\theta$  is the angular displacement of the cam (after adjustment).  $\phi'$  is the angular displacement angle of the follower (after adjustment).

By rotating the projective curves around the axis of symmetry, a 3D goblet shape can be obtained. After the rotation, the profile coordinates of the goblet were generated using coordinate transformation equations.

**2.5. Example.** In this study, goblet shapes were simulated using fourth-degree polynomial motion curves. Feature point data from existing goblets were collected and substituted as boundary conditions in equation (1). The values of  $\theta_t, \phi_m$ , and  $\phi_t$  of the polynomial segment are obtained as follows:  $\theta_t = 0.257$  rad,  $\phi_m = 0.863$  rad, and  $\phi_t = 1.382$  rad.

Substituting the aforementioned values into equation (3) yields

$$\phi(\theta) = 104.4\theta^2 - 487.1\theta^3 + 630.8\theta^4. \quad (12)$$

Figure 3 shows that the cam profile coordinates, where an origin was located on the cam axis, can be generated from (4). After rotating cam profiles with angle  $\delta$  around the adjustment axis  $(x_a, y_a)$ , the central coordinates of roller followers were derived from (7). Subsequently, a geometrical relationship analysis on cam motion curves was conducted to generate projective curves to generate new goblet shapes.



A variety of parameter  $\delta$  was applied to (7)–(12) to obtain different cam motion curves. The  $x$  and  $y$  coordinates were multiplied by constants, and the current units were converted to length units. A  $90^\circ$  clockwise rotation was performed to generate goblet body projective curves (Figure 4). Figure 4 illustrates the goblet body projective curves 1–6 generated by applying various parameter  $\delta$  ( $0^\circ$ ,  $4^\circ$ ,  $8^\circ$ ,  $12^\circ$ ,  $16^\circ$ , and  $20^\circ$ , respectively) to the cam motion curves. The goblet bottom projective curve was then incorporated into the goblet body projective curves to obtain the complete goblet projective curves (Figure 5).

### 3. Kansei Engineering

In this study, by reviewing the adjectives on the goblets in the relevant literature studies [49, 50] and adding the opinions of product design experts, three adjectives that describe the goblets are selected: valuable, gentle, and streamlined. Four product design experts were invited to evaluate these adjective degrees of goblets designed using the parametric design method (Table 1). These product design experts include 3 men and 1 woman, all of whom are doctoral students in the Department of Industrial Design, with more than 5 years of product design experience. The adjective degrees of the three adjectives were surveyed. The Likert five-point scale was used to calculate the points. The format of Likert five-point item includes strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree. Interviews were used to record the degrees of the three adjectives of the experts on the goblets. The average degrees for each adjective were as follows: for goblet 1, the “valuable” degree was 2.25, the “gentle” degree was 4, and the “streamlined” degree was 2. For goblet 2, the “valuable” degree was 3, the “gentle” degree was 3.25, and the “streamlined” degree was 2.75. For goblet 3, the “valuable” degree was 4, the “gentle” degree was 3.75, and the “streamlined” degree was 4.75. For goblet 4, the “valuable” degree was 4, the “gentle” degree was 4, and the “streamlined” degree was 4. For goblet 5, the “valuable” degree was 2.5, the “gentle” degree was 3.25, and the “streamlined” degree was 4.25. The most “valuable” feeling was goblet 3 and goblet 4. The most “gentle” feeling was goblet 1 and goblet 4. The most “streamlined” feeling was goblet 3 (Table 1).

In [41–48], adjective degrees were determined by respondents or experts after they observed products, entities, or pictures. A product entity or picture is required to rate adjective degrees. In this study, the continuous change of a single parameter was applied to product design, thereby designing a series of styles for goblets. Some goblets were selected to determine adjective degrees by experts. Adjective degrees for goblets that had not been selected were determined through interpolation (Figure 6). This method allowed us to obtain the adjective degree for each design. Using the interpolation method to determine adjective degrees can reduce the time required for observing products and giving scores. For example, when  $\delta = 7^\circ$ , the “valuable” degree was 2.81, the “gentle” degree was 3.44, and the “streamlined” degree was 2.56. In [41–48], scores were used to determine the adjective degrees of individual

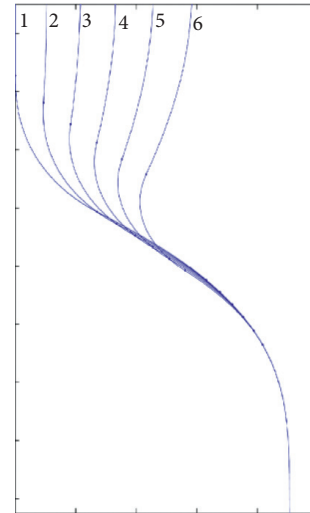


FIGURE 4: Goblet body projective curves.








FIGURE 5: Complete goblet projective curve.

products. In this study, using percentages to determine adjective degrees was proposed, and a triangular graph was created for three adjectives (Figure 7) to record percentages for adjectives. Dot 1 denotes goblet 1, dot 2 denotes goblet 2, and so on. Thus, the internal characteristics of products can be clearly presented. For example, when  $\delta = 4^\circ$  (goblet 1), the percentage of the “valuable” degree was 27.3%, the percentage of the “gentle” degree was 48.5%, and the percentage of the “streamlined” degree was 24.2%. The triangular graph shows the percentage of the adjective degrees of the goblet produced by different values of  $\delta$  (Figure 7). Subsequently, a questionnaire was administered to customers, and their preferences for the three adjectives describing goblets were counted and the corresponding values of  $\delta$  were found.

These complete goblet projection curves were rotated around the axis of symmetry to create various goblet shapes, which were used to produce 3D goblet models for 3D printing (Figure 8). Designers can use adjective degrees in Kansei engineering to determine which goblet satisfies market demand.

TABLE 1: The adjective degree of the goblet.

Goblet projective curve	Goblet 1 ( $\delta = 4^\circ$ )	Goblet 2 ( $\delta = 8^\circ$ )	Goblet 3 ( $\delta = 12^\circ$ )	Goblet 4 ( $\delta = 16^\circ$ )	Goblet 5 ( $\delta = 20^\circ$ )
					
Valuable	2.25 (27.3%)	3 (33.3%)	4 (32%)	4 (33.3%)	2.5 (25%)
Gentle	4 (48.5%)	3.25 (36.1%)	3.75 (30%)	4 (33.3%)	3.25 (32.5%)
Streamlined	2 (24.2%)	2.75 (30.6%)	4.75 (38%)	4 (33.3%)	4.25 (42.5%)

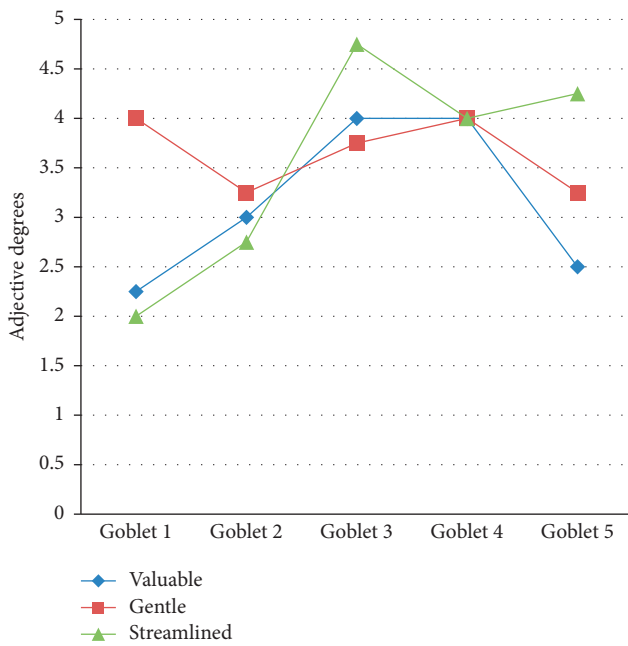


FIGURE 6: The adjective degrees of the three adjectives.

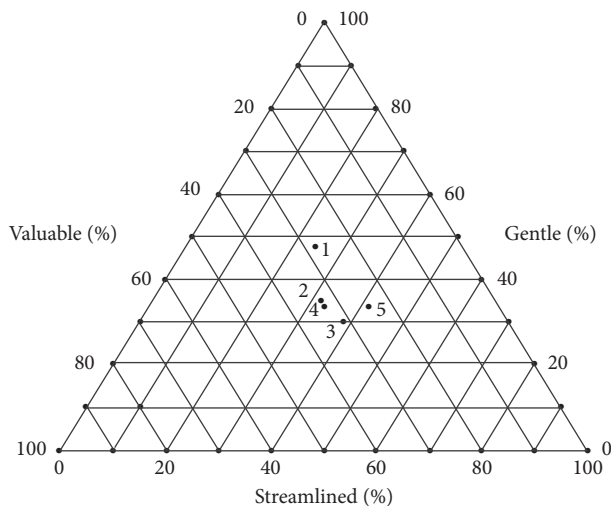


FIGURE 7: Triangular graph of adjective degrees.



FIGURE 8: 3D goblet model.

#### 4. Discussion

In this study, we developed a novel design method for goblet styling based on a parametric design and Kansei engineering. The parametric design was used for shape generation, and Kansei engineering was used for shape evaluation. This section compares the differences between the methods presented in this paper and those presented in the literature.

Parametric design performs styling by defining feature points. There are two methods for setting up the parameters that determine product appearance: the first method defines feature points by using coordinates, whereas the second method defines feature points by using the ratios of different components in product appearance. For the first method, after the feature points have been defined, they are connected using mathematical equations to form the curves of the product's appearance. The currently used approach of adjusting the curves of appearance involves changing the coordinates of the feature points while retaining the feature point coordinates. The approach proposed by this study changes the curves through mathematical conversion. The

physical aspect of mathematical conversion in this case is changing the curves by adjusting the cam through manipulation of the cam mechanism. Compared with the existing method, the one proposed in this research is able to provide multiple product appearances by adjusting only one parameter; however, it cannot be used for products that have complex curves.

In the traditional shape evaluation method [37–45], adjective degrees are determined by respondents or experts after observing product entities or pictures. A product entity or picture is required to rate adjective degrees. In this study, the continuous change of a single parameter was applied to the product design of a series of styles for goblets. Some goblets were selected to determine adjective degrees by experts. Adjective degrees for goblets that were not selected were determined through interpolation. Therefore, this method can predict the adjective degrees of products which are yet to be designed.

## 5. Conclusion

In this study, we developed a computer-aided goblet design method for creating the designs of goblets by using a parametric design and Kansei engineering. Adjustable cam motion equations, transformation coordination, cam profile data compilation, and motion curve analysis were used for the design of goblet styling. After collecting feature point data from existing goblets to define the boundary conditions of cam motion equations, a single parameter was adjusted to generate various projective curves. Kansei engineering was used for shape evaluation. This study improved the method for determining adjective degree scores and records. Adjective degrees can be obtained through interpolation to reduce the time required by experts to observe products and determine scores. Adjective degrees can be converted into percentages illustrated in the triangular graph to clearly present the characteristics of products. After the analysis of the customer's preferences, the goblet styles that satisfy market demand can be selected for mass production. The proposed design method can be applied to the design of other axis-symmetrical products with simple styles.

The following points merit further discussion:

- (1) With reference to relevant literature, the present study provided three adjectives which are used to describe the design of goblets. Follow-up studies can use other adjectives as well.
- (2) This study conducted a sampling survey on clients and delivered questionnaires to gather the clients' preferences among the three adjectives used to describe goblets and determine the  $\delta$  value among the three. This study introduces the conceptualization of an approach that has not yet been performed but can be implemented in follow-up studies.
- (3) In other studies, absolute numbers were used to indicate adjective degrees. The current study indicated adjective degrees by using relative numbers as percentages. Follow-up studies are advised to evaluate the differences between the two methods when designing products.

## Data Availability

The raw/processed data required to reproduce these findings cannot be shared at this time due to technical or time limitations.

## Conflicts of Interest

Chii-Zen Yu and Fong-Gong Wu declare that there are no conflicts of interest regarding the publication of this manuscript.

## References

- [1] F. Y. Chen, *Mechanics and Design of Cam Mechanism*, Pergamon Press, New York, NY, USA, 1982.
- [2] C. E. Wilson and J. P. Sadler, *Kinematics and Dynamics of Machinery*, Harper Collins College Publishers, New York City, NY, USA, 1993.
- [3] D. M. Tsay and H. M. Wei, "A general approach to the determination of planar and spatial cam profiles," *Journal of Mechanical Design*, vol. 118, no. 2, pp. 259–265, 1995.
- [4] J. H. Shin, C. M. Lee, and J. S. Kim, "Shape design of disk cam mechanism using instant velocity centers," in *Proceedings of the 6th Symposium on Transport Phenomena and Dynamics of Rotating Machinery*, vol. 1, pp. 178–186, Honolulu, HI, USA, February 1996.
- [5] J. H. Shin, D. W. Kang, J. S. Kim, and D. W. Kim, "A study on shape design approach of disk cams using relative velocity of follower," *Journal of the Korean Society for Precision Engineering*, vol. 17, no. 2, pp. 185–192, 2000.
- [6] J. H. Shin and Y. H. Zhang, "A computation approach to profile generation of planar cam mechanisms," *Journal of Mechanical Design*, vol. 126, no. 1, pp. 183–188, 2004.
- [7] A. Biswas, M. Stevens, and G. L. Kinzel, "A comparison of approximate methods for the analytical determination of profiles for disk cams with roller followers," *Mechanism and Machine Theory*, vol. 39, no. 6, pp. 645–656, 2004.
- [8] H. Zanzerl, "Stamping apparatus with improved ejection mechanism," French Patent 2,412,403, 1979.
- [9] O. M. Nedschroef, "Machine for upsetting bolts and similar articles," United States Patent 3,688,322, 1972.
- [10] F. Stehr, "Die ejector assembly for multi-stage forming machines," United States Patent 4,552,525, 1985.
- [11] S. Yoshiuchi, "Multistage heading machine," Japan Patent 2,002,361,357, 2002.
- [12] C.-F. Chang, "Synthesis of adjustable four-bar mechanisms generating circular arcs with specified tangential velocities," *Mechanism and Machine Theory*, vol. 36, no. 3, pp. 387–395, 2001.
- [13] H. Zhou and K.-L. Ting, "Adjustable slider-crank linkages for multiple path generation," *Mechanism and Machine Theory*, vol. 37, no. 5, pp. 499–509, 2002.
- [14] T.-M. Wu and C. O.-K. Chen, "Mathematical model and its simulation of exactly mechanism synthesis with adjustable link," *Applied Mathematics and Computation*, vol. 160, no. 2, pp. 309–316, 2005.
- [15] A. Ahmad and K. J. Waldron, "Synthesis of adjustable planar 4-bar mechanisms," *Mechanism and Machine Theory*, vol. 14, no. 6, pp. 405–411, 1979.
- [16] S. Krishnamoorthy and A. J. Kothadiya, "Intersecting inflection circles in adjustable mechanisms," *Mechanism and Machine Theory*, vol. 22, no. 2, pp. 107–114, 1987.

- [17] S. J. Wang and R. S. Sodhi, "Kinematic synthesis of adjustable moving pivot four-bar mechanisms for multi-phase motion generation," *Mechanism and Machine Theory*, vol. 31, no. 4, pp. 459–474, 1996.
- [18] H. Zhou, "Synthesis of adjustable linkages for precise function generation using the optimal link length adjustment," in *Proceedings of the 31st Mechanisms and Robotics Conference*, vol. 8, pp. 503–509, Las Vegas, NV, USA, 2007.
- [19] G. R. Penock and A. Israr, "Kinematic analysis and synthesis of an adjustable six-bar linkage," *Mechanism and Machine Theory*, vol. 442, pp. 306–323, 2009.
- [20] A. Sedano, R. Sancibrian, A. Juan, F. Viadero, and F. Egana, "Hybrid optimization approach for the design of mechanisms using a new error estimator," *Mathematical Problems in Engineering*, vol. 2012, Article ID 151590, 20 pages, 2012.
- [21] S. R. Wilhelm and J. V. Ven, "Design and testing of an adjustable linkage for a variable displacement pump," *Journal of Mechanisms and Robotics*, vol. 5, no. 4, 2013.
- [22] S. R. Wilhelm and J. V. Ven, "Adjustable linkage pump: efficiency modeling and experimental validation," *Journal of Mechanisms and Robotics*, vol. 7, no. 3, 2015.
- [23] W. M. Hwang and C. Z. Yu, "Optimal synthesis of the adjustable knock-out cam-follower mechanism of a bolt former," *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, vol. 219, no. 8, pp. 767–774, 2005.
- [24] M. Hauschild and R. Karzel, *Digital Processes*, Actar, New York, NY, USA, 2011.
- [25] S. Krish, "A practical generative design method," *Computer-Aided Design*, vol. 43, no. 1, pp. 88–100, 2011.
- [26] Y. Shan, X. M. Zhou, X. M. Tan, J. Z. Zhang, and Y. H. Wu, "Parametric design method and performance analysis of double S-shaped nozzles," *International Journal of Aerospace Engineering*, vol. 2019, Article ID 4694837, 24 pages, 2019.
- [27] W. Jabi, *Parametric Design for Architecture*, Laurence King Publishing, London, UK, 2013.
- [28] R. Woodbury, *Elements of Parametric Design*, Routledge, Abingdon, UK, 2010.
- [29] J. Frazer, "Parametric computation: history and future," *Architectural Design*, vol. 86, no. 2, pp. 18–23, 2016.
- [30] K. Liu, X. Zeng, J. Wang et al., "Parametric design of garment flat based on body dimension," *International Journal of Industrial Ergonomics*, vol. 65, pp. 46–59, 2018.
- [31] C. J. Lin, "Developing narrative diagrams for algorithmic modeling of architectural parametric design," *Computer-Aided Design and Applications*, vol. 17, no. 2, pp. 447–457, 2020.
- [32] J. W. Zhan, "Cam Motion Equations in Automobile Styling Design System," M.S. thesis, National Cheng Kung University, Taiwan, China, 2003.
- [33] A. Łukaszewicz, "Modelling of solid part using multibody techniques in parametric CAD systems," *Solid State Phenomena*, vol. 147–149, pp. 924–929, 2009.
- [34] Y. Bodein, B. Rose, and E. Caillaud, "A roadmap for parametric CAD efficiency in the automotive industry," *Computer-Aided Design*, vol. 45, no. 10, pp. 1198–1214, 2013.
- [35] J. D. Camba, M. Contero, and P. Company, "Parametric CAD modeling: an analysis of strategies for design reusability," *Computer-Aided Design*, vol. 74, pp. 18–31, 2016.
- [36] R. Oxman, "Thinking difference: theories and models of parametric design thinking," *Design Studies*, vol. 52, pp. 4–39, 2017.
- [37] A. Łukaszewicz, K. Panas, and R. Szczebiot, "Design process of technological line to vegetables packaging using CAx tools," in *Proceedings of 17th International Scientific Conference on Engineering for Rural Development*, pp. 871–876, Jelgava, Latvia, May 2018.
- [38] G. Lobaccaro, A. H. Wiberg, G. Ceci, M. Manni, N. Lolli, and U. Berardi, "Parametric design to minimize the embodied GHG emissions in a ZEB," *Energy and Buildings*, vol. 167, pp. 106–123, 2018.
- [39] S. Chang, N. Saha, D. Castro-Lacouture, and P. Pei-Ju Yang, "Generative design and performance modeling for relationships between urban built forms, sky opening, solar radiation and energy," *Energy Procedia*, vol. 158, pp. 3994–4002, 2019.
- [40] E. Gunpinar, U. C. Coskun, M. Ozsipahi, and S. Gunpinar, "A generative design and drag coefficient prediction system for sedan car side silhouettes based on computational fluid dynamics," *Computer-Aided Design*, vol. 111, pp. 65–79, 2019.
- [41] A. Horiguchi and T. Suetomi, "A Kansei Engineering approach to a driver/vehicle system," *International Journal of Industrial Ergonomics*, vol. 15, no. 1, pp. 25–37, 1995.
- [42] S.-J. Luo, Y.-T. Fu, and P. Korvenmaa, "A preliminary study of perceptual matching for the evaluation of beverage bottle design," *International Journal of Industrial Ergonomics*, vol. 42, no. 2, pp. 219–232, 2012.
- [43] M. Nagamachi, "Development of a design support system for office chair using 3D graphics," *International Journal of Industrial Ergonomics*, vol. 15, pp. 49–62, 1995.
- [44] K. C. Wang and F. R. Ju, "An innovative design methodology KKBDCa for affective product development," *Mathematical Problems in Engineering*, vol. 2013, Article ID 629708, 10 pages, 2013.
- [45] T. Jindo and K. Hirasago, "Application studies to car interior of Kansei engineering," *International Journal of Industrial Ergonomics*, vol. 19, no. 2, pp. 105–114, 1997.
- [46] H. J. Lai, T. C. Tung, and K. L. Huang, "Sedan form and visual angle to consumers of attraction influence," *Journal of Cultural and Creative Industries Research*, vol. 1, pp. 39–48, 2011.
- [47] K. Nakada, "Kansei engineering research on the design of construction machinery," *International Journal of Industrial Ergonomics*, vol. 19, no. 2, pp. 129–146, 1997.
- [48] F. Guo, W. L. Liu, F. T. Liu, H. Wang, and T. B. Wang, "Emotional design method of product presented in multi-dimensional variables based on Kansei engineering," *Journal of Engineering Design*, vol. 25, no. 4–6, pp. 194–212, 2014.
- [49] Y. C. Hsu, "Applying parametric of forms to computer-aided product Form knowledge base: a case study on wine glass design," M.S. thesis, National Yunlin University of Science and Technology, Taiwan, China, 2009.
- [50] Y. C. Chen, S. R. Li, and L. T. Tseng, "The relationship between shapes and Kansei words-A goblet study," *Visual Arts Forum*, vol. 11, pp. 76–99, 2016.