Select the Best Surface Fitting Approach for the Reconstruction of High Quality 3-D Objects from Range-image Data

Ralph W. L. Ip, Angela C. W. Yeung, Felix T. S. Chan and Henry C. W. Lau

Abstract— **Applying surface fitting models to reconstruct 3-D objects with free-form features is widely employed from toy industry to medical surgery. However, reconstruction of free-form surfaces from range-image data always prone to intensive manual operations, and some technical skills are always needed. Recently, research focus on the studies of improving surface reconstruction results to achieve better quality with simple processing procedures. The research aims to report some strategies that provide guidelines to select appropriate surface fitting models for achieving the required quality at the shortest time. The surface fitting models including Extrusion, Revolution, Sweeping, Coons and Loft were detailed examined and compared with their abilities in the reconstruction of primitive 3-D objects. Findings of the research illustrated that the listed fitting models could work well for a specific group of object surfaces. A shorter surface reconstruction time and better fitting result can be achieved from the recommended fitting models. A table categorizes surface fitting models provide the best fitting to various shape primitive 3-D objects. Successfully apply the proposed surface fitting selection approach can simplify intensive learning of various surface modelling tools, and also build up confidence for unskilful designers in the using sophisticated computer-aided surface modelling software.**

Index Terms— **Fitting, Free-form shape, Range-image data, Surface reconstruction**

I. INTRODUCTION

Select an appropriated surface modelling method for the fitting of a group of range-image data is an important research topic for surface design work. There are some fitting models can be used in reconstruction of surfaces, and the simplest and commonly used include extrusion, revolution, sweep, Coons and Loft. Recently, some research study the enhancement of surface modelling principle [1]-[3], little research focus on selecting appropriated models to give the best fitting of object surfaces. Geometrical shape of the modelled objects will dominate which surface fitting models to be used. Skilful designers will spend less time in model selection but it always cause problems for non-skilful people. In order to facilitate the decision-making process on surface model selection, a research was conducted to work out the dependences on choosing an appropriated fitting model. Firstly, characteristics of the five common surface fitting models were studied. Then, a group of five primitive 3-D objects was identified and fitted by the models. A comparison was performed to find out deviations in terms of accuracy, computing time and numbers of information required for different fittings by the five models. Findings from the research suggested some guidelines in assisting the chosen of an appropriated fitting model for the best result of the given range-image data, and to form a good 3-D object surface.

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II. COMPARISON WITH DIFFERENT SURFACE FITTING MODELS

Generation of surfaces always is starting from points and curves. Curves can be generated from points, and surfaces can be generated from curves [4]-[5]. There are some developed fitting models to generate a curved surface, and each model has its own characteristics and requirements. A selection of five common range-image data fitting models; and their differences in surface generation are given in Table I.

Table I Comparison on five common surface fitting models

Fitting models	Surface generation methods	Information required
Extrusion	A curve moves in a specified direction	A 3-D curve
Revolution	A curve rotates along a primary axis	1 primary axis and 1 3-D curve
Sweep	A generator moves along a path curve	2 or 3 3-D curves

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Coons	Four boundary curves	4 curves to form a closed area
Loft	Parallel boundary curves travel along the same direction	2 or more parallel curves

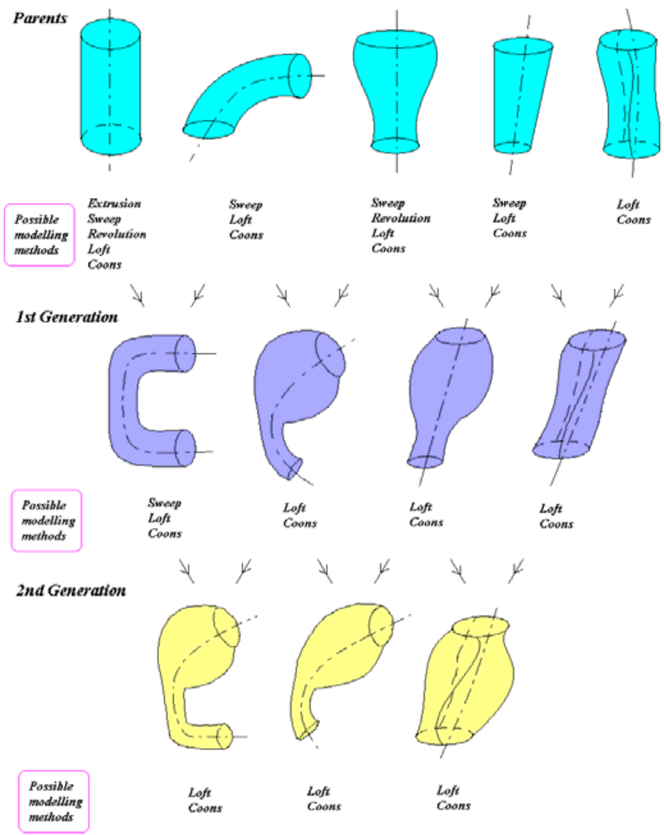


Fig. 1 A generation chart for 3-D objects.

It is true that some 3-D object surfaces can be generated by two or more different fitting models. Fig. 1 shows a generation chart of some 3-D objects that were developed from five primitive objects, and they can be created by one of the five fitting models, i.e. extrusion, revolution, sweep, Coons and Loft. Surface shape of the discussed primitive objects in this research is classified as cylinder, elbow, bottle, cone and free-form. The 1st generated objects are formed from mixed features of two primitive objects. The 2nd generated objects are formed from combined features of two 1st generated objects. It can be seen that more fitting models can be used for the primitive objects, and only the Coons and Loft are used for the 2nd generated objects. Information as illustrated in Fig. 1 shows that some kind of 3-D object surfaces can only be created from unique fitting models. The aim of the research is to find out what rules or principles can be based upon in the choosing of appropriate fitting models for each specific kind of primitive 3-D objects.

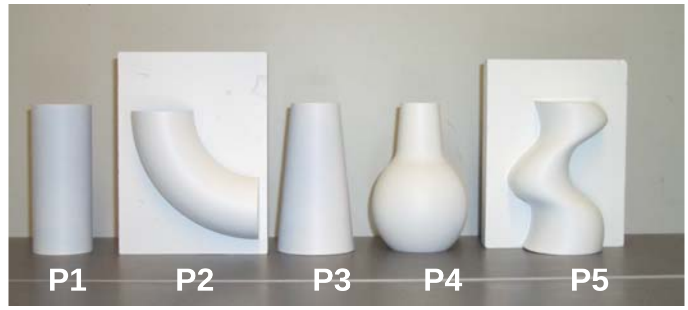


Fig. 2 Five primitive 3-D objects used for trials on comparison with different surface fitting models.

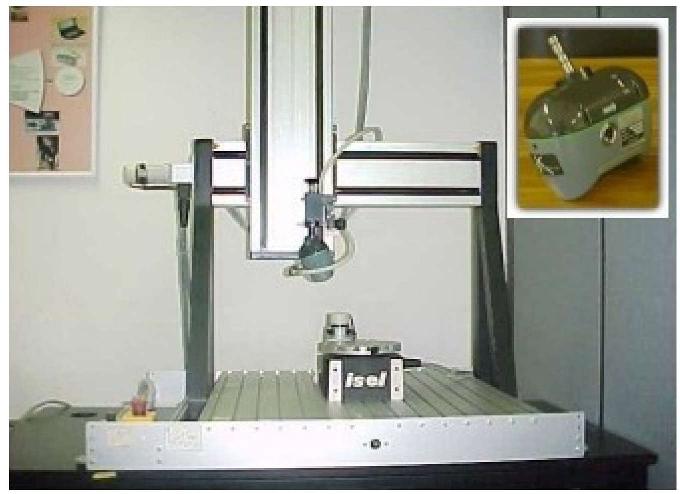


Fig. 3 The laser scanning machine used for range-image data capturing.

III. GENERATION OF PRIMITIVE 3-D OBJECTS BY DIFFERENT FITTING MEODELS

Research studies have performed to find differences among the primitive 3-D objects created from the five different surface fitting models as discussed.

As illustrated in Fig. 2, a group of five primitive 3-D objects were manufactured and used for a comparison with surface generation from various surface fitting models. Surfacer [6] was used as the computing-aided modelling tool for each of the surface generation. In the trials, half of the object surfaces were scanned on a 3-axis laser scanner as shown in Fig. 3. The captured range-image data were used to generate the object surfaces by various fitting models including extrusion, revolution, sweep, Coons and Loft. Results of surface fitting are illustrated in the following figures, and a comparison among the accuracy, computing processing time and information required is listed.

a. The cylindrical shape primitive (P1)

Figs. 4(a)-4(e) illustrated results of fitting for the primitive object 1 (P1) as shown in Fig. 2. Five of the fitting models were employed. The computing time and average error of each fitted surface are listed in Table II.

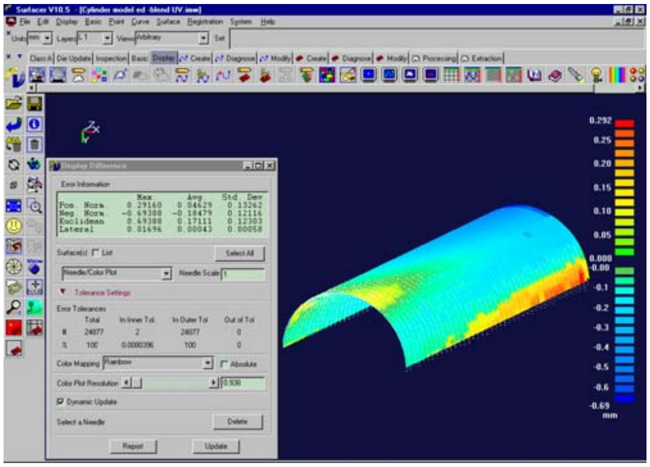


Fig. 4(a) Error plot of object type P1 created by extrusion.

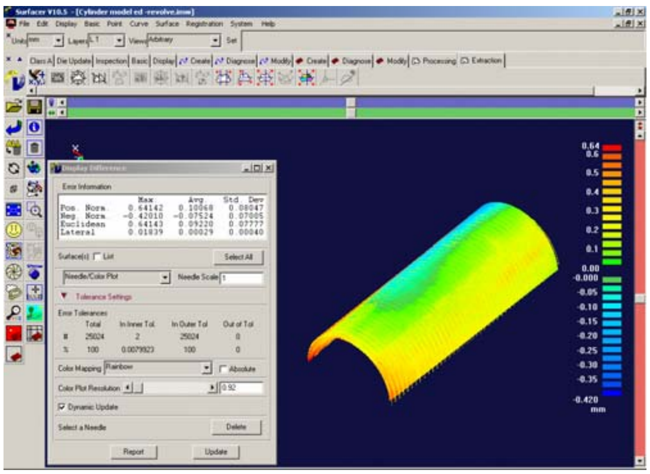


Fig. 4(b) Error plot of object type P1 created by revolution.

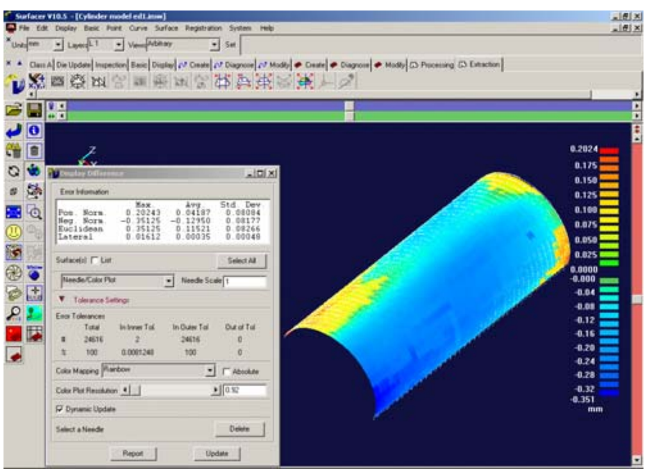


Fig. 4(c) Error plot of object type P1 created by sweep.

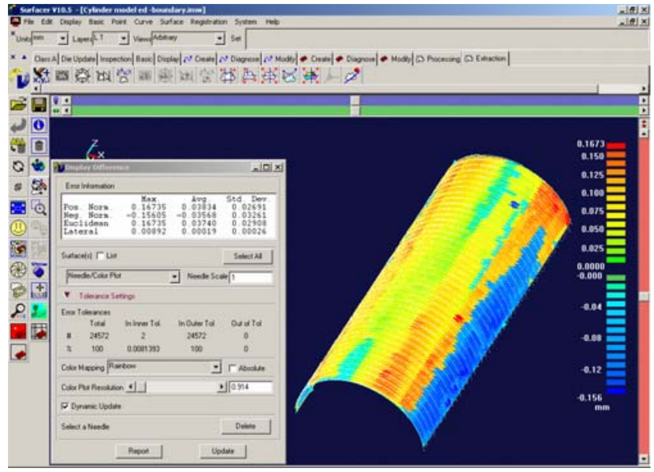


Fig. 4(d) Error plot of object type P1 created by Coons.

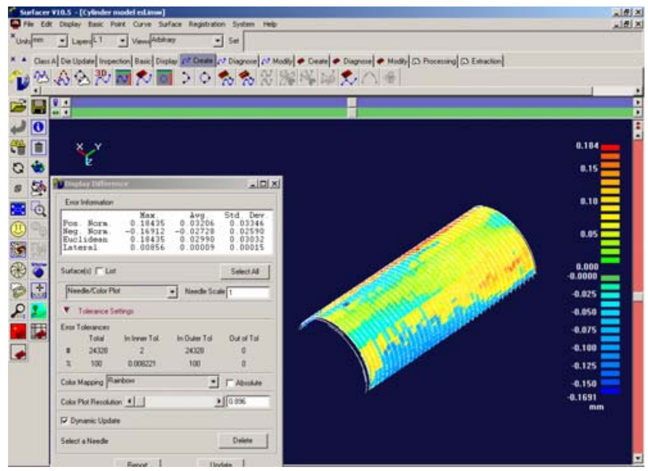


Fig. 4(e) Error plot of object type P1 created by Loft.

Table II Result summary of each fitting for object type P1

Fitting models	Time (s)	Information provided	Average errors (mm)
Extrusion	15	One curve	0.115540
Revolution	28	One curve and an axis	0.087960
Sweep	30	One generator one path curve	0.085685
Coons	46	Four boundary curves	0.037010
Loft	45	Three cross sectional curves	0.029670

Fig. 5 is the statistical chart to show trial results as listed in Table II. It indicates the average errors of the fitted surfaces using Coons and Loft models are less than extrusion, revolution and sweep models, but more computing time is needed.

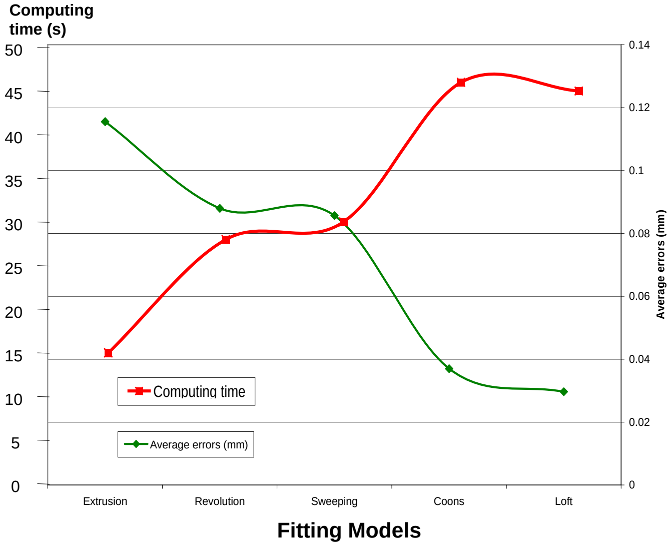


Fig. 5 Statistical chart of trial for the fitting of P1 objects.

b. The bottle shape primitive (P4)

Trials for bottle shape primitive 3-D object (P4) are given in Fig. 6(a)-6(d).

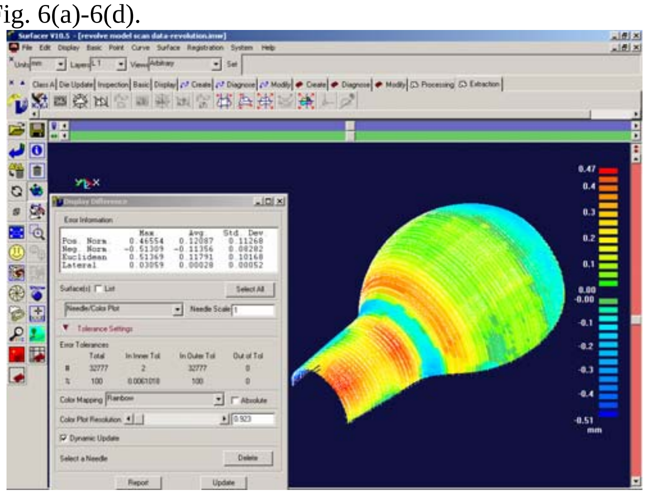


Fig. 6(a) Error plot of object type P4 created by revolution.

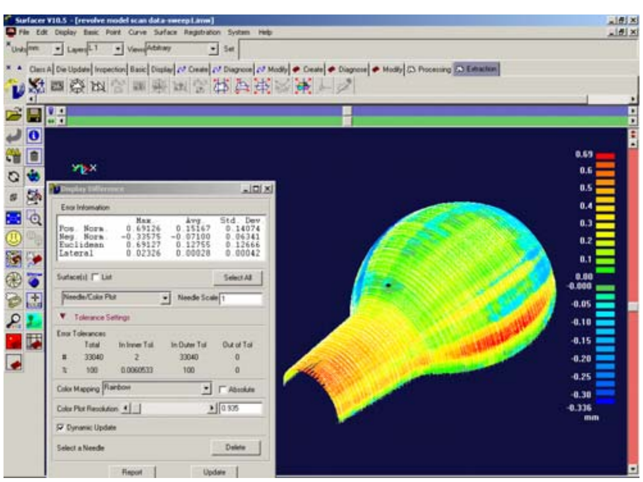


Fig. 6(b) Error plot of object type P4 created by sweep.

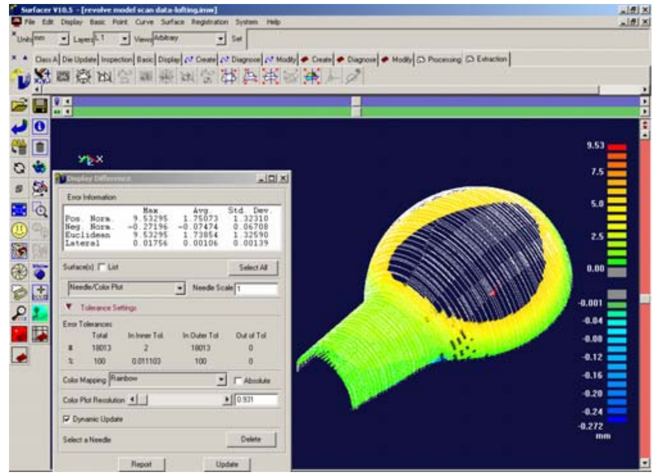


Fig. 6(c) Error plot of object type P4 created by Coons.

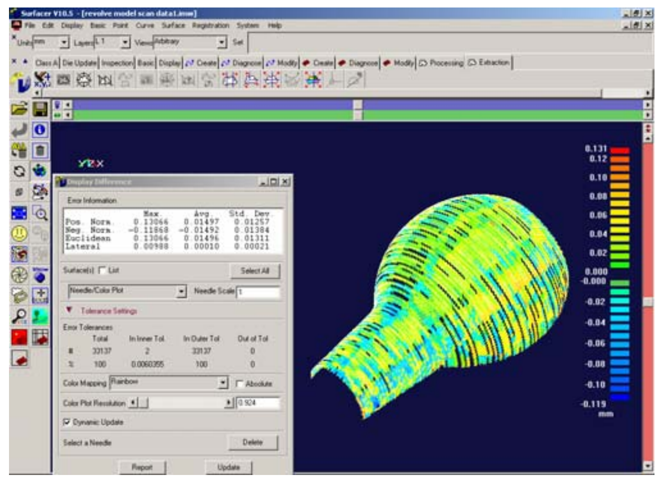


Fig. 6(d) Error plot of object type P4 created by Loft.

Bottle shape primitive object surfaces can be created by four fitting models that include revolution, sweep, Coons and Loft.

Table III lists computing time and average errors of each surface generation result from the four fitting models. Results show that Loft fitting model provides the best result in comparison with the others, and the computing time is still the longest.

Table III Result summary of each fitting for object type P4

Fitting models	Time (s)	Information provided	Average errors (mm)
Revolution	32	One curve and an axis	0.117215
Sweep	36	One generator and one path curve	0.111335
Coons	51	Four boundary curves	0.091274
Loft	62	Ten cross sectional curves	0.014945

c. The free-form shape primitive (P5)

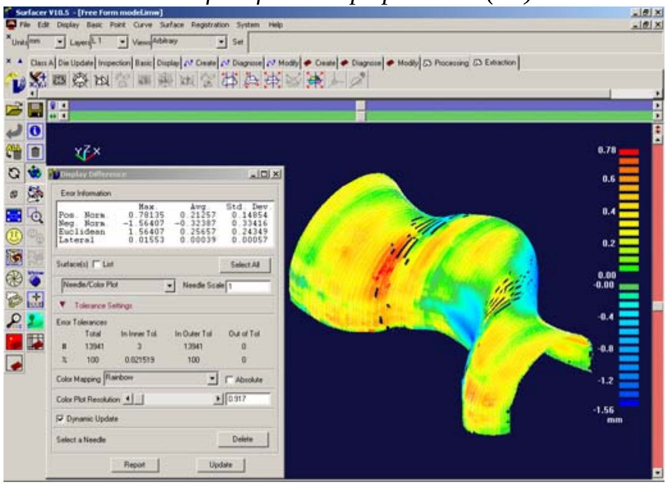


Fig. 7(a) Error plot of object type P5 created by Coons.

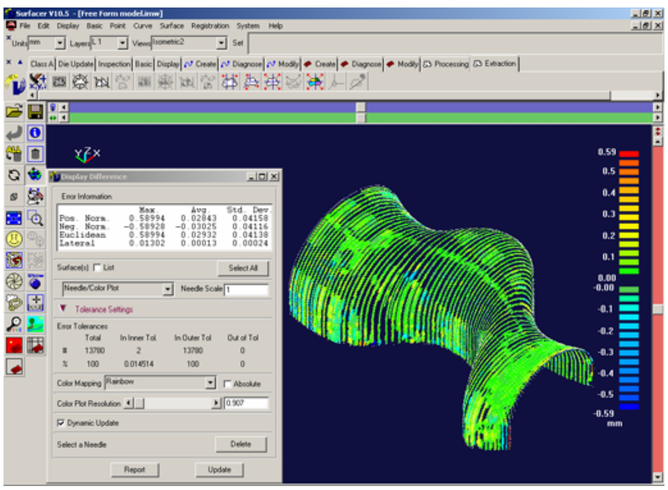


Fig. 7(b) Error plot of object type P5 created by Loft.

Figs 7(a) and 7(b) compare fitting errors between Coons and Loft models for the free-form shaped primitive (P5). Results as listed in Table IV show that the computing time for Loft model is nearly double of Coons, and the accuracy is about ten times of Coons.

Similar trials have also been done for primitive objects P2 (elbow) and P3 (Cone). Results for these two kinds of primitive objects are listed as shown in Tables V and VI.

Table IV Result summary of each fitting for object type P5

Fitting models	Time (s)	Information provided	Average Errors (mm)
Coons	55	Four boundary curves	0.26822
Loft	96	Twenty cross sectional curves	0.02934

Table V Result summary of each fitting for object type P2

Fitting models	Time (s)	Information provided	Average Errors (mm)
Sweep	40	One generator curve and two path curves	0.250310
Coons	46	Four boundary curves	0.266295
Loft	55	Ten cross sectional curves	0.027450

Table VI Result summary of each fitting for object type P3

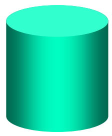
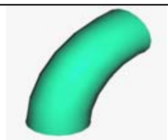
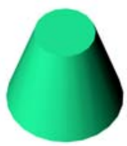
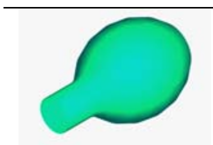
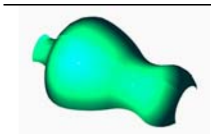
Fitting models	Time (s)	Information provided	Average Errors (mm)
Revolution	31	One curve and an axis	0.21849
Sweep	39	One generator curve and two path curve	0.09787
Coons	54	Four boundary curves	0.03201
Loft	63	Ten cross sectional curves	0.02938

IV. GUIDELINES FOR THE CHOOSING OF APPROPRIATED FITTING MODELS

Results as demonstrated in Fig. 1 show that complicated shape surfaces can be generated from a crossed mixing between any two primitive objects of P1 to P5. The five primitive 3-D objects can also be generated from the five surface fitting models. However, results of each fitting will be different among the applied models in terms of accuracy, computing time and information required. Designers can refer to the listed trial results in this research to select an appropriate fitting model. A summary of a comparison with different fitting models used for different primitive objects is given in Table VII. A set of guidelines as deduced from information of Table VII are listed as follows:

(a) If ***time*** is not restricted, then ***'Loft'*** model is suggested for all kinds of primitive objects due to its accurate properties.
(b) If ***time*** is restricted and ***accuracy*** is a must, then '***Coons***' model is suggested for primitive objects P1 and P4.
(c) If ***time*** is restricted and ***accuracy*** is concerned, '***sweep***' model can be considered for objects P1 to P4 although its fitting accuracy cannot as good as ***"Coons"*** and '***Loft***'.
(d) If '***time'*** is restricted, '***extrusion***' and '***revolution***' models can also be used for the corresponding primitive objects.

Table VII Summary of various fitting models used for the five groups of primitive 3-D object.

Fitting models Primitive objects	Extrusion	Revolution	Sweep	Coons	Loft
 P1	▪ The fastest and simplest ▪ Require 1 fitting curve ▪ Large fitting errors	▪ Second fast ▪ Requires 1 curve and 1 axis ▪ Fairly accurate of fitting	▪ Computing time similar to revolution ▪ Require 2 curves ▪ Fitting accuracy similar to revolution	▪ A longer computing time ▪ Requires 4 curves ▪ Accurate fitting results	▪ Computing time similar to Coons ▪ Requires 2 or more curves ▪ Highly accurate fitting results
 P2	▪ Cannot be applied for such primitive objects	▪ Cannot be applied for such primitive objects	▪ The fastest ▪ Requires 2 curves ▪ Less accurate than Coons and Loft	▪ Second fast ▪ Requires 4 curves ▪ Less accurate than Loft	▪ Computing time is the longest ▪ Requires 10 or more curves ▪ Highly accurate fitting results
 P3	▪ Cannot be applied for such primitive objects	▪ The fastest and simplest method ▪ Requires 1 curve and 1 axis ▪ Less accurate than others	▪ A slightly faster than revolution ▪ Requires 3 curves ▪ A slight accurate than revolution	▪ Requires fairly much of time ▪ Requires 4 curves ▪ Accurate similar to sweep	▪ Requires a longer time than Coons ▪ Requires 10 or more curves ▪ Highly accurate of fitting
 P4	▪ Cannot be applied for such primitive objects	▪ The fastest ▪ Requires 1 curve and 1 axis ▪ Less accurate than others	▪ The second faster method ▪ Requires 3 curves ▪ Moderate accurate	▪ Require fairly much of time ▪ Requires 4 curves ▪ A fairly high accuracy	▪ Requires a longer time ▪ Requires 10 or more curves ▪ Highly accurate of fitting
 P5	▪ Cannot be applied for such primitive objects	▪ Cannot be applied for such primitive objects	▪ Cannot be applied for such primitive objects	▪ Require less time ▪ Requires 4 curves ▪ Less accurate	▪ Require a longer time ▪ Requires 20 or more curves ▪ Accurate of fitting

V. CONCLUSION

Research on recommending the best fitting models to common shape primitive 3-D objects is studied. Five basic groups of primitive objects were examined, and they include cylinders, elbows, bottles, cones, and free-form shape. In fact that by mixing these basic primitive objects, complex shape object surfaces can be produced. Therefore, research study has investigation on the fitting of the five primitive objects using five common surface fitting models. A surface model tool namely Surfacer was used to facilitate each of the fitting process. Trial results for the primitive objects are listed in tables for further analysis on the chosen of appropriate fitting models. It is clear that Coons and Loft model can be used for all kinds of primitive objects but a longer computing time is generally required. Extrusion, revolution and sweep models will be suitable for specified groups of object, and provide an acceptable accuracy at the shortest computing time. No unique model is provided for each group of object surface, designers should define the basic criteria including computing time, accuracy and available information for surface generation before the chosen of the fitting models. Guidelines as provided by this research are an analytical summary from all trials, and form a reference to shorten the surface design cycle time, especially for the inexperienced designers.

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