Shape Recognition Technique for High-accuracy Mid-surface Mesh Generation

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Abstract: Computer Aided Engineering (CAE) is an essential technology in the process of automotive development. In term of mesh generation for structural analysis of resin products, it has been a challenge to generate high quality mid-surface mesh automatically because of the difficulty to create high quality mid-surface calculated from 3D CAD. This paper introduces a new method of extracting mid-surface aiming to generate high quality mid-surface mesh. Recognition of end-terminal surfaces plays an important role for mid-surface generation, and hereby Offset and SURF techniques are being studied and compared in terms of recognition accuracy. This technique has been proved to be able to recognize end-terminal surface with high-accuracy. This new method has achieved in extracting high quality mid-surface mesh automatically, and improving the efficiency of the whole process for CAE modelling.

Keywords: Mid-mesh, Automation, Shape recognition, Mesh control

1. Introduction

Recently, the necessity to cut time and cost in product development cycle is becoming important in CAE market as a production strategy evolved into many kinds in small quantity. Also, it is predictable that social problems such as depopulation, a declining birth rate and an aging population will cause man-power shortage and engineering skill deterioration as the number of retiring skilled workers keeps increasing. To answer the market and social changes mentioned above, automation of CAE process that has a knowledge database gained from skilled workers and fast-computing system is demanded [1].

The whole CAE process is composed of three parts: pre-process, analysis process, and post-process. Pre-processing is a process to generate mesh model from 3D CAD data that will be used for analysis computation. In case of sheet metal or resin products, mid-mesh modeling is the most accepted way for modeling. The main focus of this paper is on the automation and speeding-up of pre-processing modeling especially for mid-mesh generation process.

Several different approaches to generate mid-mesh automatically has been proposed in [2][3]. Medial Axis Transform (MAT) is one of the well-known methods, which calculates the mid-surface from the wall-thickness information of 3D model [4][5]. Quadros and Shimada proposed Chordal Axis Transform (CAT), using bubble packing algorithm to firstly generate one-layer tetra mesh and then divide the tetra mesh right in the middle to create mid-surface [6]. Sheen et.al, proposed a method by detecting face-pairs at first and generating mid-surface from the recognized face-pairs through offset [7]. The method of face-pairs has an advantage for more flexibility on controlling mid-mesh generation based on any specific rules. However, the traceability problem and imperfect result are more likely to occur in the case of complicated shapes of 3D-CAD data, and for this reason manual modification/repair is needed. The inexistence of mid-surface reference that is needed for manual repair is the main obstacle, where the mid-surface has to be created by hand and sometimes it is not easy. Depending on the shape complexity, a tremendous time is needed for mesh modification process due to the tedious manual repair work and therefore it is difficult for speed-up modelling time without automation.

In general, geometry simplification is recommended before the mid-surface generation process, where the unnecessary features such as fillets at the bottom of ribs and others are eliminated manually. As a first step for automation and speed-up of high-quality mid-mesh generation, a new method called "SURF" technique was developed for automatically recognizing geometry features [8][9]. This technique can be utilized to recognize basic features such as end-terminal, rib, flange, and many others. Also, this method can be applied to recognize the unnecessary features that have to be eliminated during geometry simplification process. Therefore, the geometry simplification process can be automated and the manual work load can be reduced.

This paper serves as an investigation and evaluation of the automatic recognition of the above-mentioned unnecessary features during mid-mesh generation process. Among several other features, the discussion and study on this paper will focus only on the recognition of end-terminal surfaces, which is considered as the most important feature for mid-mesh generation. To obtain recognition results with high-accuracy, a hybrid method of "SURF" in combination with other algorithms are applied [9].

In this paper, a new shape recognition technique "Offset technique" was proposed, and the capability of Offset and SURF techniques for use in shape recognition is introduced. Finally, experimentation of SURF technique for shape recognition were compared and tested with 3D plate-like models.

2. Shape recognition technique

In this section, two methods of shape recognition, offset and SURF technique, are studied. Section 2.1 provides the outline of Offset technique to recognize end-terminal surfaces. Section 2.2

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gives the brief introduction and general methodology of SURF technique for the recognition of end-terminal surfaces.

2.1 Offset technique

Offset technique is used to recognize shape features by evaluating the changes of surface area for each offset step. Offset process is executed with the direction facing to the inner side of the model (refer to Fig. 1). The end-terminal surfaces tend to have a larger change in surface area in comparison to the other surfaces. In other words, the area of end-terminal surfaces has a tendency to go to zero along the offset process. All surfaces that are smaller than the threshold angle φ_T have a high probability as end-terminal surfaces.

However, it is not easy to fix the value for φ_T because the offset area ratio is different depending on the geometry contours. The variance of offset area ratio for different models will cause instability if the recognition of end-terminal surfaces is determined only by the threshold value. The decision on the recognition of end-terminal based on threshold value is prone to misjudging. In addition, models with complicated contours will show irregular changes of offset area ratio, which may cause ambiguity for its reliability and accuracy. Due to the above-mentioned restrictions, it is necessary to consider carefully the value of φ_T. Furthermore, since the offset has to be repeated several times for the observation of surface area changes, this method is not an efficient method in term of computation time. Also, computation time will increase as the model size grows larger.

2.2 SURF technique

SURF technique was invented with the purpose to recognize features/shapes efficiently and accurately. Utilizing SURF technique will improve both the calculation time and also the recognition accuracy. SURF technique has a function to calculate the edge connection between two adjacent surfaces of 3D CAD models (see Fig. 4). By referring to this edge connection information, geometry shapes/features can be simply recognized by analyzing the patterns of edge connection collections. Edge connection is calculated as

$$\text{edge connection} = (\mathbf{v} \times \mathbf{n}_T) \cdot \mathbf{n}_A \qquad (1)$$

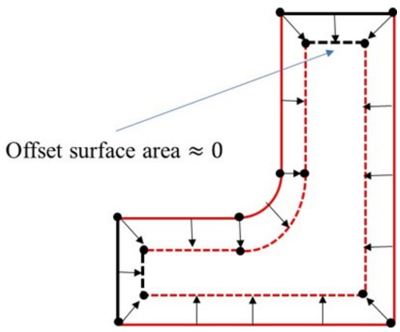


Fig. 1 Offset technique for recognition of end-terminal surfaces.

where **v** indicates the vector of the direction of edge shared between two adjacent surfaces A and T. $\mathbf{n}_T$ and $\mathbf{n}_A$ represent the normal vector of each surface, which is calculated in the vicinity of shared edge. Edge connection calculated by Eq. (1) can be classified into three types as shown in Fig. 5.

- Edge connection > 0 is concave connection (Fig. 5a).
- Edge connection < 0 is convex connection (Fig. 5b).
- Edge connection = 0 is planar connection (Fig.5c).

In the case of end-terminal surfaces, edge connection between two adjacent surfaces is comprised of convex-convex connections as shown in Fig.6. This characteristic of end-terminal surfaces defined by SURF technique can be helpful to solve the recognition problems in Offset technique. Improvement in recognition accuracy and computation time can be expected by adopting SURF technique.

SURF technique is applicable not only for recognizing end-terminal surface, but it can also be extended to recognize ribs, flanges and many other shapes/features. Also, the other advantage of using SURF technique over Offset method is the reduction in computation time because of its capability to find any types of features with much less computation power thus making it highly efficient. The details about using SURF technique for recognizing various types of geometry features is given in [8].

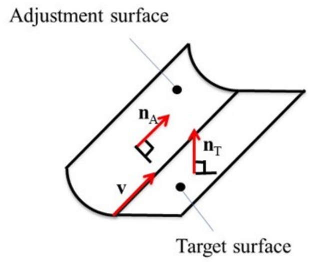
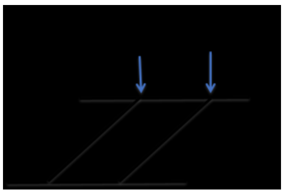


Fig. 4 Calculation of surface connection using SURF technique.

(a) Concave connection (b) Convex connection



(c) Planar connection

Fig. 5 Edge connection; (a) concave connection, (b) convex connection and (c) planar connection.

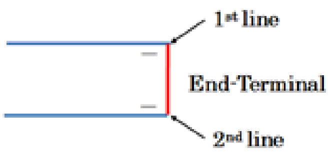


Fig. 6 Recognition rule for end-terminal surface by relating to surface connection calculated by SURF technique

3. Shape recognition examples

In this section, shape recognition using SURF and Offset technique are experimented for its capability to recognize end-terminal surfaces. The evaluation and validation of recognition accuracy are done using a sample models shown in Fig. 7. The equation to find φ_T and offset distance x of Offset technique is given in Eq. (2) and (3), respectively.

$$\varphi_T = \cos^{-1}\left(\frac{1}{\sqrt{1+N_{MAX}{}^2}}\right) \quad (2)$$

$$x = \frac{T_{MAX}}{2N_{MAX}} \quad (3)$$

Where, T_{MAX} defines the maximum thickness of a model and N_{MAX} is the maximum offset number. x is solved using Eq. (3), and then φ_T is calculated from Eq. (2). In the case of models with simple contours, N_{MAX} is defined as 21.

The recognition result of end-terminal surfaces using both Offset and SURF technique shows model is shown in Fig. 8. The actual total number of end-terminal surfaces possessed by model B is 77, and the experiment for offset and SURF technique showed a similar result where all the 77 surfaces could be recognized properly. However, three other surfaces which are not actually end-terminal surfaces was also recognized. Although there is an error of excessively recognized surfaces, the result is acceptable and can be implemented for practical use for mid-mesh generation because this recognition error was considered unimportant and has no direct influence in mid-mesh generation.

This result provides a confirmation and validation of the effectiveness and potential of SURF technique for improving the accuracy of end-terminal surfaces. For future implementation, a tremendous reduction of processing time can be expected by using only SURF technique for shape recognition without Offset technique. Using SURF technique to find the convex-convex connections for end-terminal surfaces will be much easier and will save a lot of time. An experiment to validate the recognition accuracy and calculation time using SURF technique only is excluded in this paper.

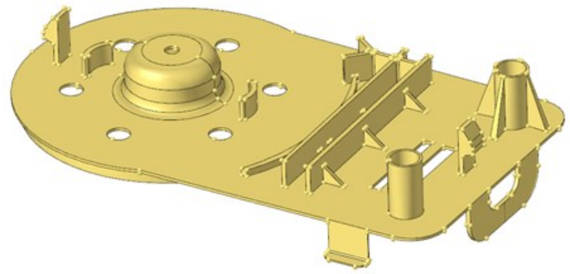


Fig. 7 Sample model for shape recognition experimentation.

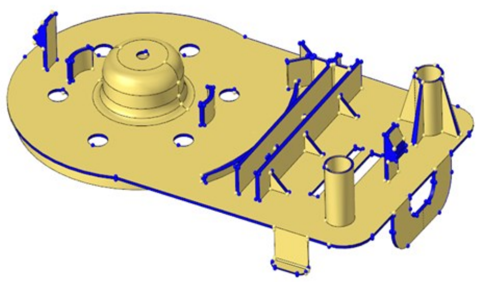


Fig. 8 Recognition results of model B using Offset technique and SURF technique.

4. Conclusion

In this paper, "Offset" technique was proposed as a new method for shape recognition of end-terminal surfaces and the advantages of using "Offset" along with "SURF" technique was introduced. The validation of recognition accuracy was carried out through experiments using a sample model. The implementation of shape recognition using SURF technique for mid-mesh generation is summarized as follows:

1) Offset technique is a method to recognize features through the evaluation of offset surface area changes towards the inner side of 3D plate-like models. Since the changes of surface area differ depending on the complexity of model contours, the recognition result is mostly affected by the determination of φ_T (the threshold angle; section 2.1). Therefore, the selection of φ_T is a vital part in Offset technique.
2) SURF technique is a method to recognize feature shapes based on a calculation of edge connection (concave, convex and planar connection) of 3D CAD model, which has been proved for its capability and effectiveness for the recognition of end-terminal surfaces.
3) Comparative study using SURF technique also shows an improved accuracy.
4) Finally, improvement in the recognition of end-terminal surfaces also gives a better result for mid-mesh generation.

SURF technique has a high potential for shape recognition and improves the geometry traceability during mid-mesh generation. Faster computation time and improved accuracy will finally reduce the amount of manual work, where high-efficiency and faster modeling process can be expected. Moreover, the error caused by the difference in human operators' expertise can be eliminated through the automation of mid-mesh generation using SURF technique.

Further improvement and innovation are still necessary for better shape recognition and mid-mesh generation results. The development for effective and high-speed algorithms is undergoing to answer the challenge of rapid changes in market demands.

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Acknowledgments Thanks to the Japanese automobile makers for their collaboration, evaluation and valuable feedback on the improvement of meshing efficiency for thin-walled components.

