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Simulated rolling method for the recognition of outer profile faces of aircraft structural parts

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ABSTRACT

Outer profile faces of aircraft structural parts are important features for machining and inspection. Universal feature recognition methods are not effective in recognizing these features, a simulated rolling method which is specially used to recognize outer profile faces of aircraft structural parts is proposed accordingly. Imagine that there is a vertical, infinite and elastic revolving roller outside of a part placed horizontally. The roller moves towards the part under the gravitation of the part. When the roller touches the outer profile, pressure force and frictional force are generated. Then the roller starts to roll along the outer profile of the part under the action of the resultant force until it comes back to the position where it touches the outer profile for the first time. Outer profile faces are selected automatically on demand of the practical engineering application from the faces which contact the roller during rolling process. The testing results show that this method is effective in recognizing outer profile faces, and the recognition accuracy can be improved by adjusting the parameters of the method.

1. Introduction

Most aircraft structural parts are slab-like. Machining features are mostly concentrated on the top and bottom sides of the parts. And the outermost sides which have fewer machining features are the parts' outer profiles composed of curved and planar faces. Taking the thickness direction of a part as the vertical direction, the outer profile is the boundary of the part in the horizontal direction, and outer profile faces are the outermost faces of the part in the horizontal direction accordingly. Generally, outer profile faces of some aircraft structural parts such as integral frame parts are related to the shape of the aircraft, while outer profile faces of some structural parts such as integral panels affect the aircraft assembly. Therefore, outer profile faces of structural parts are important machining and inspection features.

Automatic feature recognition is a necessary procedure of computer-aided process planning and inspection planning. Outer profile faces do not have any common and definite topologic or geometric attributes like other types of features. For example, holes all have cylindrical and concave faces, while the bottom faces and sidewall faces of all pockets are always connected by concave edges if there is no feature intersection. But outer profile faces can be surfaces with arbitrary form. Besides, the topologic and geometric relationships between outer profile faces are not fixed. Moreover, some outer profile faces intersect with other features seriously. Hence, universal feature recognition methods are not effective in recognizing outer profile faces of aircraft structural parts. Graph-based method [1–3] constructs an attributed adjacency graph (AAG) of the part firstly. Then subgraphs are extracted from the AAG and matched to feature patterns in library to achieve feature recognition. Compared to other feature classes, outer profile faces do not have specific topologic or geometric attributes, and the topologic and geometric relationships between profile faces are also indefinite. Hence, the pattern of outer profile faces cannot be built, and so graph-based method cannot be used to recognize outer profile faces. Volumetric decomposition approach [4–7] decomposes the delta volume (the difference between a blank and the finished part) into cells, and then combines cells to produce feature instances. Generally, a recognized feature instance is a volume that can be removed in a single tool path. Hence, this approach is difficult to recognize non-volumetric features like outer profile faces of aircraft structural parts. Hint-based approach performs extensive geometric reasoning from features' hints, and finally constructs feature instances [8]. Because outer profile faces of aircraft structural parts do not have the hints distinguished from other feature classes' and geometric reasoning is difficult, they are hardly recognized by this method. The approach [9–11] which interactively defines and automatically recognizes features has the same problem as graph-based method. Hybrid approach [12,13] is more effective than above methods. It establishes rules for each feature class. Then, features are identified by geometric

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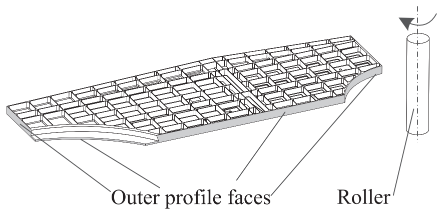

Fig. 1. Part and roller.

reasoning and matching rules. It is difficult to establish rules which define outer profile faces of aircraft structural parts precisely. Hence, outer profile face recognition accuracy of hybrid approach is not high. Other universal feature recognition methods such as viewer-centred approach [14,15], tool-centric approach [16,17] and artificial intelligence approach [18,19] all have difficulties in recognizing outer profile faces of aircraft structural parts correctly. Compared to above feature recognition methods, slicing method [20–22] is more effective in recognizing outer profile faces of structural parts. Firstly, the part is sliced by a set of parallel planes to generate slices. Each slice comprises of one or more closed contours generated by the intersection of corresponding cutting plane and the part. Secondly, features are identified by analyzing the information of the contours in successive slices. Another research team in the same laboratory as the authors employs slicing method to recognize outer profile faces of aircraft structural parts. Outermost contours in each slice are clipped and combined to generate a biggest contour to extract outer profile faces of the structural part. Because the biggest contour is closely related to the positions of each slice, the recognition accuracy is not high if there are complicated curved faces on the outer profile of the structural part.

Therefore, this paper proposes a simulated rolling method (SRM) used to recognize outer profile faces of aircraft structural parts specially. As shown in Fig. 1, we assume that there is a vertical, infinite and elastic roller outside of a structural part placed horizontally. The roller always revolves around its axis. All faces of the part are discretized into dense points. Gravitational force is exerted on the roller, which moves towards the point nearest to it. When the roller touches the point, pressure force and frictional force are generated. The resultant force causes a small displacement of the roller in the direction of the force. Afterwards, the new nearest point is searched and the force exerted on the roller and the new displacement of the roller are calculated. The face which the nearest point is situated on is a potential outer profile face. This process is repeated until the roller returns to the position where the roller touched a discrete point for the first time. Finally, the needed outer profile faces are selected from potential outer profile faces on demand of practical engineering application.

2. Principle of SRM

2.1. SRM

According to the practical engineering application, SRM needs to set the filter criterion of outer profile faces in advance. Generally, this criterion is that the angle between an outer profile face's average normal and the vertical direction has to be greater than or equal to a specified value in order to exclude approximately horizontal and horizontal faces. Because it is improper to consider these faces outer profile faces, although they are potential outer profile faces. How much the filter value is depends on the practical engineering application. Examples will be given in Section 4. The main steps of SRM are as follows. Firstly, discretize all faces of the part into dense points. The density is defined by the largest distance L between all neighboring discrete points. The less L, the denser the points will be. Secondly, initialize the roller's position. The roller has to be outside of the part and not intersect with the part. It can be ensured by the following method: compute the circumscribed sphere of the bounding box of the part; afterwards, place the roller anywhere outside of the circumscribed sphere. Thirdly, simulate the roller's rolling around the outer profile of the part. The details of the rolling process are as follows.

The roller's structure is shown in Fig. 2. There are a rigid shaft whose radius is R in the center of the roller and an elastic layer whose thickness is T outside of the shaft. The roller is always vertical and infinite and revolves directionally around its axis. The force and movement state of the roller is shown in Fig. 3. Please notice that all the 2D figures in this article are views of projections on the horizontal plane, that is, the horizontal plane is the paper plane in all the 2D figures. The distance between the roller axis and the nearest discrete point is d. If $d \geqslant R + T$, the roller is not compressed by the discrete point, and its radius is $r = R + T$. If $d < R + T$, the roller is compressed. We assume that the elastic layer of the roller shrinks evenly around its axis, and it has the same deformation as that of the position where it is compressed by the discrete point along its axis, i.e. the roller is still cylindrical. Hence its radius $r = d$. The magnitude of pressure force $\boldsymbol{F}_{\mathrm{p}}$ is set to

$$|\boldsymbol{F}_{\mathrm{p}}| = \begin{cases} 0 & d > R + T \\ K_{\mathrm{e}}\left(\frac{1}{d-R} - \frac{1}{T}\right) & R < d \leqslant R + T \\ +\infty & 0 \leqslant d \leqslant R \end{cases} \quad (1)$$

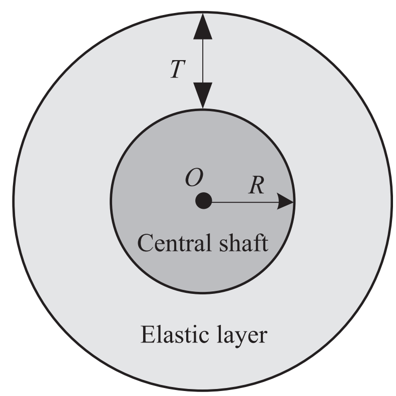

Fig. 2. Roller structure.

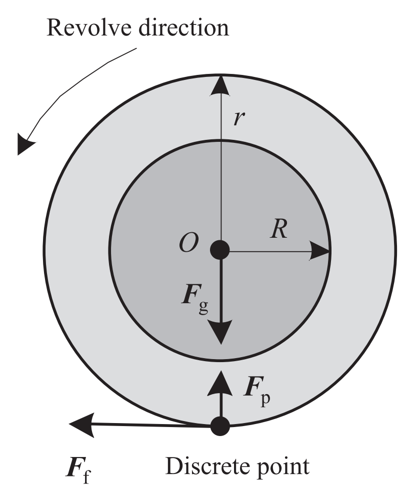

Fig. 3. Force and movement state of the roller.