A Casting Retrieval Method Based on Cavity and External Shape Features

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Abstract: Model retrieval is one of the key technologies in parts management for the reuse of casting process and design. However, current retrieval schemes usually treat parts as a whole, thereby neglecting the impact of part cavities on functionality and manufacturing. This study has investigated an encoding method based on the cavity features of parts. The external shape feature and cavity features are extracted through cavity filling and connected domain algorithms. These features are integrated with the volume and modulus to enable a formulation of casting feature coding. Then a retrieval system based on model input was created, utilizing a specified coding similarity calculation algorithm. Experiments show that it is possible to obtain the desired results within the top 2 retrieval results. This significant enhancement had substantially improved both the efficiency and accuracy of the retrieval process.

Keywords: casting retrieval; cavity features

1 Introduction

3D CAD models have been the basic form of data for modern advanced manufacturing. Efficient 3D model retrieval is instrumental in the domain of parts management. Moreover, it is also beneficial for the design of new parts and new processes for manufacturing [1]. The content-based model retrieval, which utilizes 3D models as the input for retrieval, is favorably conducive to the parts management. It is a research area of significant interests within the domain of model retrieval. The key of content-based retrieval methods lies in the computation of model features through feature extraction algorithms, utilizing the similarity between features to represent the similarity between models. For instance, content-based retrieval methods represent 3D models by employing techniques such as surface distance statistics [2], reflective symmetry [3], topological structures [4], skeletal structures [5], and maximum inscribed sphere decomposition graphs [6], among others to calculate the similarity of models. These descriptive methods treat the model as an indivisible entity. Nevertheless, in casting production, the internal cavities of components are typically formed by sand cores, and the external shape are formed by the molds. Both the cavities and the shape are of equivalent significance in the function and the manufacturing process of parts. Therefore, in the study, an approach has been introduced for casting retrieval by synthesizing characteristics of both the cavities and external shapes.

2 Experimental procedure

Casting Feature Encoding

Considering various factors that influence the casting process, the encoding structure of the casting's process features is depicted in Figure 1. It contains modulus, volume, and structural code with external shapes and cavities of parts.

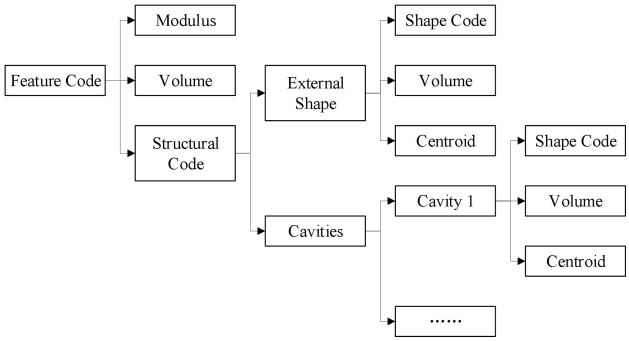

Figure 1 Casting feature code with external shape and cavities of model

To compute the feature encoding of the casting, the initial step involves the extraction of the cavity from the model. In this methodology, the model is normalized by the pose-normalization method [7] and projected onto planes along the three principal axes – X, Y, and Z. Then, a statical analysis is conducted to determine the maximum and minimum values for each point along the principal axes within the projection. Subsequently, the interior of the 3D model is filled with the intermediate content between these maximum and minimum values. Finally, the cavities in the model are obtained by performing a difference operation between the filled model and the original model as shown in Figure 2. Although the cavities extracted is composed of several non-adjacent entities, these cavities are marked as a whole, as shown in Figure 2(c).

Each entity within the cavity and the external shape entity devoid of cavities are subjected to the computation of their respective shape feature coding, volume and centroid position. These computations are then systematically organized in accordance with the structure delineated in Figure 1, thereby yielding the feature encoding of the casting.

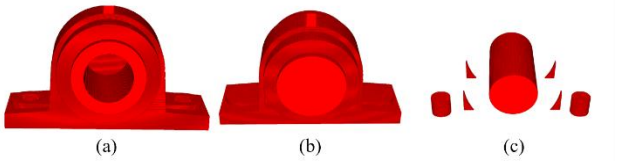

Figure 2 The model and cavities of a casting: (a) original model; (b) the filled model; (c) the cavities

Similarity Calculation

Another key aspect of model retrieval is to compute the similarity among encodings to reflect the similarity between models. In the study, KL divergence was utilized to calculate the similarity between two distinct entities, as shown in Equation (1).

$$s = \frac{1}{1+distance}$$
$$distance = \sum_{i=1}^{N} p(x_i) log\left(\frac{p(x_i)}{q(x_i)}\right) \quad (1)$$

For multiple cavity entities of parts, the similarity of entities is weighted by distance and volume. Here, volume and centroid distance represent the influence of the cavity on the part and the confidence level of the similarity. The structurally similar parts obtained ultimately need to be further screened based on volume and modulus, as these factors greatly influence the casting process design of parts.

Dataset experiments

Based on the Engineering Shape Benchmark dataset [8], the study marked 400 parts with similar levels of each other for the verification of retrieval effectiveness. The performance of a retrieval system is generally evaluated through expected reciprocal rank (ERR) in Equation (2).

$$ERR = \sum_{r=1}^{n} \frac{1}{r} PP_r = \sum_{r=1}^{n} \frac{1}{r} \left(\prod_{i=1}^{r-1} (1 - R_i)\right) R_r$$
$$R(g) = \frac{2^g - 1}{2_k}, g \in 0, 1, 2, \cdots, n-1 \quad (2)$$

where g is the similarity level of parts, k is the count of similarity level, and n is the number of retrieved parts.

3 Result and discussion

Figure 3 illustrates the impact of different volume and modulus similarities thresholds on ERR. It can be observed that as the similarity threshold increases, the performance metrics of the retrieval system improve because it eliminates more cases. However, an excessively high similarity threshold may lead to the erroneous elimination of reasonable similar parts. A reasonable similarity threshold needs to be further determined. The ERR of the retrieval results is always above 0.68, indicating that an ideal part outcome can be expected in the top 2 retrieval parts.

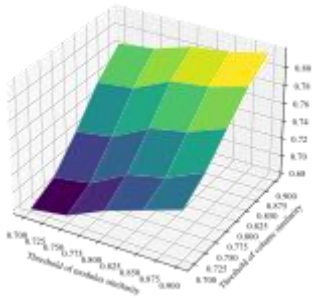

Figure 3 Influence of the similarity threshold of volume and modulus on the ERR

4 Conclusion

The study has constructed a similarity system for castings. Based on the 3D model, a cavity extraction algorithm was designed, and a method for encoding that integrated casting features and external shape features was proposed. A method for calculating the similarity of castings was proposed, and the similarity retrieval of castings was realized, lying a technical foundation for the establishment of a casting process database and intelligent design of casting processes.

References

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