Reassembling 3D Thin Shells using Integrated Template Guidance and Fracture Region Matching

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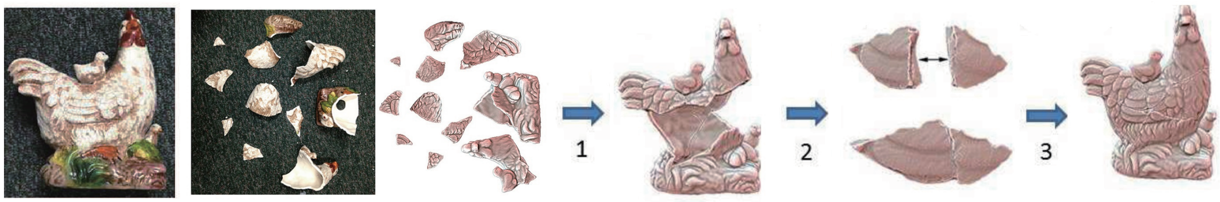

Figure 1: *A ceramic 3D model is broken into pieces. The digital scanned fragments are automatically reassembled using our pipeline.*

1 Introduction

Geometric restoration that composes 3D fragmented pieces into the original complete object is an important computer graphics and geometric processing problem. Automatic and effective restoration has applications in many fields such as archeological reconstruction, digital heritage archiving, forensic evidence processing, to name a few. For example, archaeologists reconstruct ceramic fragments (sherds) into complete pots in order to analyze the information of the ancient society. Forensic scientists reassemble skull fragments into complete skull for face reconstruction and body identification. In both of these problems we need to solve a composition of digitized thin-shell fragments with different shapes, sizes, and resolutions. This problem remains very challenging.

Existing 3D reassembly algorithms can be classified into two types: (1) reassembly based on fracture-region matching, and (2) reassembly using template guidance. Fracture-region matching approaches exploit similarities in the local fracture geometry of adjacent fragments [Huang et al. 2006]. The template guidance approaches compose fragments based on their best match to an existing model [Yin et al. 2011]. Reassembly algorithms in both categories report difficulty in processing small fragmented pieces: first, with small pieces, it is challenging to discriminate between and segment intact and fracture regions. Second, the number of uncertain potential matches tends to be big which is non-trivial to process robustly.

Main Contribution. We propose a novel graph-based reassembly algorithm that integrates both template-guidance and fracture-region matching. Reliable pairwise matchings among the fragments and template are computed to suggest potential alignments. Then through solving a multi-piece matching on a reassembly graph, composition of the fragments can be computed. Without the need to explicitly segment fracture and intact regions on the fragments, this pipeline can effectively utilize both of their geometry to recompose fragmented thin-shell objects with many and small pieces.

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2 Our Approach

Our approach has 3 steps (Figure 1): (1) initial reassembly by template matching, (2) pairwise alignment between fragments, and (3) groupwise reassembly computation and optimization.

First, we compute matching between template and each fragment: features are extracted using Intrinsic Shape Signature (ISS) and correlated using Signature of Histograms of OrienTations (SHOT), then their correspondence are refined using RANSAC. The output is potential transformations aligning fragments with template.

Then, a pairwise break region matching algorithm is proposed to compute the matchings between each two fragments F_i and F_j. First, the geometric subregions on break regions are clustered by curvature. Second, each cluster is assigned with the descriptor describing their area and roundness. Third, the correspondence between the clusters is computed by a modified graph matching algorithm which can produce multiple best solutions.

The template, fragments and their matchings are represented as a graph $G = (V, E)$. We aim to solve a transformation matrix m_i for each fragment, and find the subgraph of $G' = (V, E')(E' \subseteq E)$ such that $\forall e_{ij} \in E'$, $m_i = T_{ij} * m_j$. Meanwhile, we want to maximize a matching energy $S = S_p + \alpha S_e$ after m_i are applied on each fragment. S_p evaluates the alignments between the fragments and template, while S_e evaluates the alignments among the fragments. A constraint to prevent inter-fragment penetration is enforced. A beam search algorithm is adopted in the optimization of S to circumvent local maxima.

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