# Terracotta Reassembly from Fragments Based on Surface Ornamentation Adjacency Constraints

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**Abstract**

*This paper introduces a method that enables the reassembly of fragments with incompleteness in fracture surfaces and break-curves. The incompleteness of the fracture surfaces and break-curves, both contribute to the failure of all previous geometry-driven techniques for reassembly of 3D objects. The proposed method is preferable because it depends on the surface ornamentation-the structured feature lines, which are often complete and can provide enough surface adjacency constraints. Finally, we demonstrate the benefits of our method with the favorable results for real-world point clouds of Terracotta.*

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Modeling/Shape Matching and Retrieval—Shape Matching

## 1. Introduction

In the area of computer graphics and computer-aided design, fragments assembling provides a popular manner for reassembly of fractured objects [HFG*06]. It analyzes the geometries of the fracture surfaces or break-curves to find a globally consistent reconstruction of the original objects.

A heretofore unsolved problem of great archaeological importance is the automatic reassembly of Terracotta made by humans from the fragments found at an excavation site. The incompleteness of the fracture surfaces and break-curves, as shown in Figure 1, both contribute to the failure of the traditional techniques for reassembly of 3D objects. In this cases, even a fault tolerant partial matching between two fragments is not possible, not to mention a relatively perfect geometry-driven matching.

Therefore, an efficient and robust matching is required. This work proposes such a solution. The difference of our work is that fragments with incompleteness in the fracture surfaces and break-curves can also be reassembled according to the surface ornamentation-the structured feature lines, which are often complete and can provide enough surface adjacency constraints, and are also the clues used by archaeological expertise.

## 2. Contributions

- Enables the reassembly of fragments with incompleteness in fracture surfaces and break-curves.
- Presence of a reassembly method of fragmented objects based on structured feature lines, instead of geometry-driven.

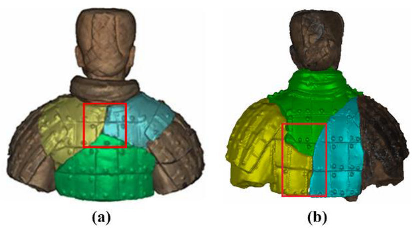


**Figure 1:** *Example of reassembly of the Terracotta. Fragments both have diverse levels of incompletenesses in fracture surfaces.*

- Features for matching are formed by neighbors of matching points, which decreases the computational costs.

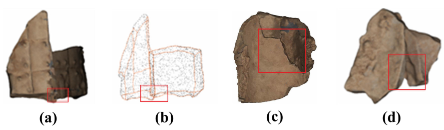


**Figure 2:** *Limitations of previous work. (a)Fragments with incompleteness. (b)Results based on break-curves. (c)(d) Results based on fracture surfaces.*

## 3. Previous work

Methods based on the break-curve matching [UT99] or based on the fractured surface matching [HFG*06] both fail to handle the



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fragments with diverse levels of incompleteness in fracture surfaces or break-curves. Although sometimes the geometry-driven reassembly method described in [MRS10] may work, it is semi-automatic.

## 4. Our method

The surface ornamentation is a set of structured feature lines that have similar properties with structured texture: locality, periodicity and the repeatability. Furthermore, the minimum structure is similar to a rectangle. We thereby use the structure information of the feature lines and the completeness of the rectangles to search matching fragments.

- Given a set of point clouds of fragments of Terracotta, the method first extracts the feature lines on the original surfaces, and thereby the structured information is represented by some typical vertices, red points and yellow points as shown in Figure 3. Red points are utilized for matching, namely matching points, whereas yellow points are utilized for representing the local features of the matching points.
- The neighbors of a matching point consist of a red point that is nearest to the matching point and a yellow point that connected with the matching point. Then a chord is form by two successive points along the contours, however, the two points should not be neighboring of each other, as shown in Figure 3. For example, the neighbors of $p_5$ are $p_2$ and $p_7$; chord $l_1$ is formed by $p_1$ and $p_2$. Therefore, chord $l_1$ is a short chord since the yellow neighboring points of $p_1$ and $p_2$ are different ($p_3$ and $p_4$ respectively), whereas chord $l_2$ is a long chord since the yellow neighboring points of $p_5$ and $p_6$ are the same ($p_7$).

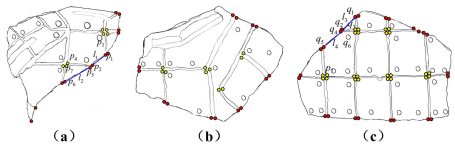

**Figure 3:** *Feature lines and typical vertices.*

- For a given fragment, each chord is matched with chords on other fragments. The error criterion is an energy function (Equation (1)), which qualifies the structure of the feature lines. $p$ and $q$ are the matching points, $N$ represents the adjacency constraint. $f$ is the matching function formed by the features of chords, including long or short, length of the chord and the direction of the chord, etc. $D$ is the errors of the completeness of the new rectangle, as shown in Figure 4(a).

$$E(f) = \sum_{p,q \in N} V_{p,q}(f_p, f_q) + \sum_{p,q \in N} D_{p,q}(f_p, f_q) \qquad (1)$$

- It does occur in practice that an incorrect match may have a smaller match-error than will a correct match. Incorrect matches may be quickly identified via two methods: 1) by validating the completeness of the reassembled rectangle, as illustrated in Figure 4(a); or 2) by validating the continuity of the structure, as illustrated in Figure 4(b).

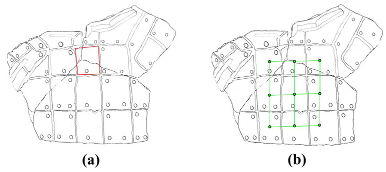

**Figure 4:** *Incorrect matching detection.*

- When matching fragments were detected, ICP method is utilized to complete the local registration. After constrained local registration, we merge the fragments of each sub-fragment into a single 'virtual' fragment for further global matching.

## 5. Results and future work

We have used several examples to test our reassembly algorithm. The input point clouds of Terracotta were scanned by a Creaform VIU handy scanner. Our goal is to match pairs of fragments with incompleteness in break curves or fracture surfaces. Therefore we performed 6 sets of reassembly results, as shown in Figure 5.

We will engage in matching the fragments on shoulders that have totally different structures of feature lines in our next work.

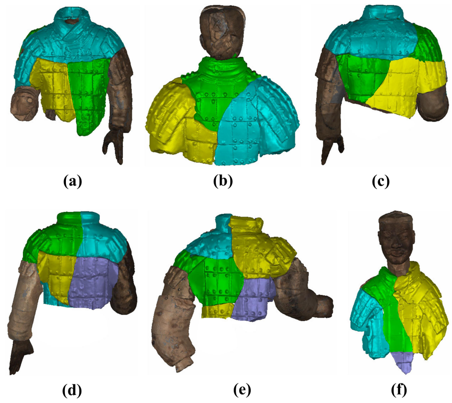

**Figure 5:** *Results of reassembly of Terracotta.*

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