Reassembling Ancient Monuments via Constrained Registration (sap_0214)

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Abstract
As demonstrated in our work [Huang et al. 2006] fracture surfaces of broken solids contain rich geometric information that are sufficient for reassembly based on geometric matching. However, the task of reassembling an ancient monument from its building blocks differs significantly from that of reassembling a broken solid. These building blocks are fragments in a much looser sense as opposing faces of neighboring stones do not contain the rich geometric features of fracture surfaces. The contribution of the present work is an algorithm for automatic reassembly of ancient monuments guided by high-level adjacent features such as edges, clamp holes, or ornaments. The data we use to test our new method comprises the remaining stones of the Octagon (Fig. 1, top, right) monument in Ephesos, Turkey, which fell apart a thousand years ago and whose reconstruction is currently undertaken.

Digital Reassembly
We scanned all currently found 150 remaining building blocks (fragments) of the Octagon and created digital 3D models (Fig. 1, top, left) from a total number of over 6000 single 3D scans. As a new contribution we implemented an out-of-core fully automatic multi-view global and local registration algorithm to cope with the large number of partial scans per fragment. Ancient monuments were often made out of hewed marble blocks that were put together without using any kind of mortar. This required a very exact hewing of the stone blocks in order to keep the slits between the blocks small. Since dowels and clamps have often been used to fix one stone onto the other, the corresponding holes in the stones are an important hint to the original position of the stone in the building. Furthermore, the 3D texture (including sharp edges and ornaments on the visible side of the building blocks) continues across neighboring stones and is thus valuable information for digital reassembly purposes. Our method extracts planar faces, straight line features, and clamp/dowels holes (Fig. 1, middle).

Building blocks are typically bounded by roughly planar faces except of the front face that might show ornaments. Thus at first we break down each fragment into several roughly planar faces \( \{ F_i \} \) using a RANSAC strategy. Then, with distance computations we determine adjacent faces and derive a directed graph \( G = (V, E) \) with the faces \( F_i \) as vertices (see Fig. 1, bottom). Vertices of adjacent faces are connected by directed edges that store feature line, clamp hole, surface roughness, and face dimension information.

Once matching faces of different fragments are determined we bring the corresponding fragments into close spatial proximity via global registration. Then we extend the multi-piece constrained local registration algorithm of [Huang et al. 2006] that performs penetration free registration (Fig. 2, bottom, middle) by the following additional constraints for adjacent fragments: (i) neighboring faces must be coplanar, (ii) neighboring feature lines must be collinear, (iii) neighboring clamp holes must be symmetrically aligned, and (iv) neighboring faces must have the same surface roughness. We include these constraints either as linear inequalities or as a penalty function. In total we get a linear constrained quadratic optimization problem that we solve with an active set method. Selected results are shown in Fig. 2.

References

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