Landmark Transfer with Minimal Graph*

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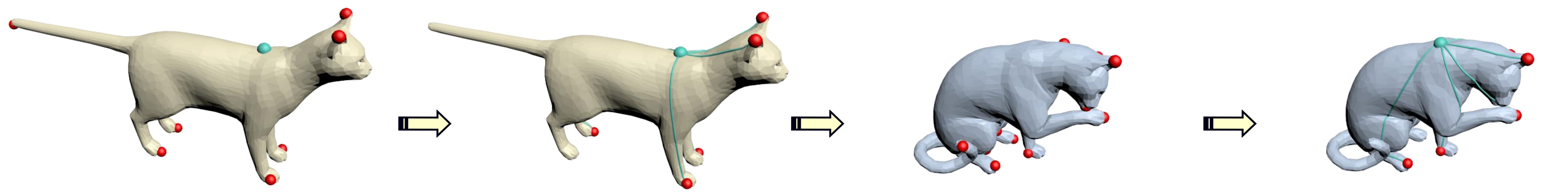


Landmark (blue) and geometric feature points (red) on the source(I) — Minimal graph on the source(II) — Geometric feature points on the target(IV) — Minimal graph and computed landmark on the target(IV)

Objectives

Given a source mesh and a set of landmarks placed by the user on the source mesh, our method computes the corresponding landmarks on a target mesh. The user-defined landmarks can be located anywhere on the source mesh; independently from geometric saliency

Approach

- Compute modified intrinsic wave descriptor[1] and convexity value for each vertex on the source; extract feature points on the source (I)
- Build minimal graph G_M on the source mesh, whose nodes are the set of selected feature points and edges are composed of geodesic paths. G_M is uniquely defined over the mesh, it is as small as possible in terms of number of nodes and geodesic distances, it defines uniquely user-provided landmark (II)
- Apply graph matching (III) to verify uniqueness of G_M
- Build feature graph G_T on the target (IV). Having both graphs, we find mapping between them via approximate graph matching (III). With graph correspondence done and with knowledge of geodesic distances from the nodes of the graph, we identify the appropriate location of user-defined landmark on the target

Challenges

- When a user is interested in characterization and selection of points on a mesh without a strongly distinguishable geometric saliency, we often rely on manual labeling
- In such cases, existing techniques on landmark extraction and matching does not guarantee a persistent set of landmarks across multiple sets of meshes
- Since the work spent on manually labeling and associating landmarks is tedious and time consuming, we develop techniques to help with reuse of the landmarks defined by the user, thereby consistency can be assured regardless of geometric distinctiveness of the landmarks

I. Feature Point Extraction

A. Local descriptor

Intrinsic wave descriptor [1] is isometry invariant and fast to compute

$$D_x = (l_1/2\pi\cdot r_1, l_2/2\pi\cdot r_2, ..., l_{16}/2\pi\cdot r_{16})$$

where l_i is the length of geodesic iso-line, and r_i is its corresponding geodesic radius (Fig.1).

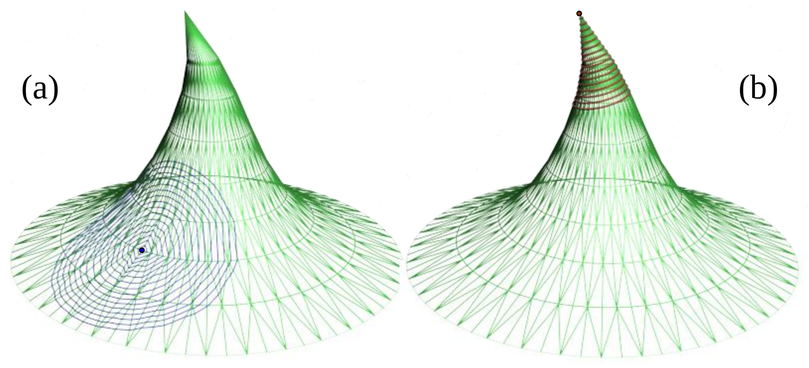
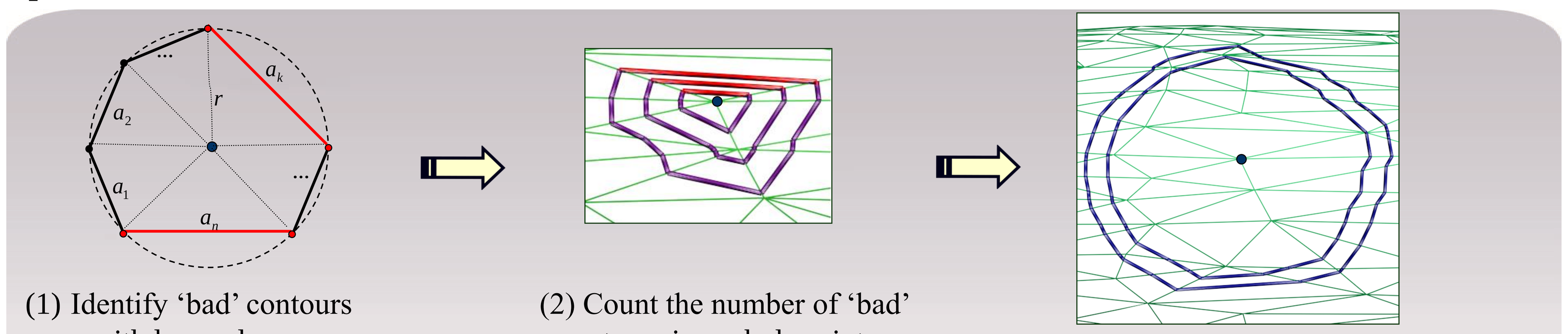


Fig. 1. Iso-contours of the wave descriptors for vertices for locally flat (a) and sharp (b) surface neighbourhood

B. Modified local descriptor

In order to make intrinsic wave descriptor more robust to topology changes, we go through next steps:



(1) Identify 'bad' contours with long edges $\exists i : a_i \geq \alpha\cdot 2\pi\cdot r, \alpha\in(0,1)$ — (2) Count the number of 'bad' contours in each descriptor — (3) Remove 'bad' contours

C. Compute convexity

Convexity $C_x = \left\| D_x - (1,1,...,1)^T \right\|_2$ value shows how much a local neighborhood of a vertex is different from the flat surface (Fig. 2).

D. Cluster and extract geometric feature points

Retain top *K* vertices with highest convexity values and group them according to convexity similarity and geodesic proximity into clusters. Then extract one feature point from each cluster whose average geodesic distance to all others in cluster is maximal.

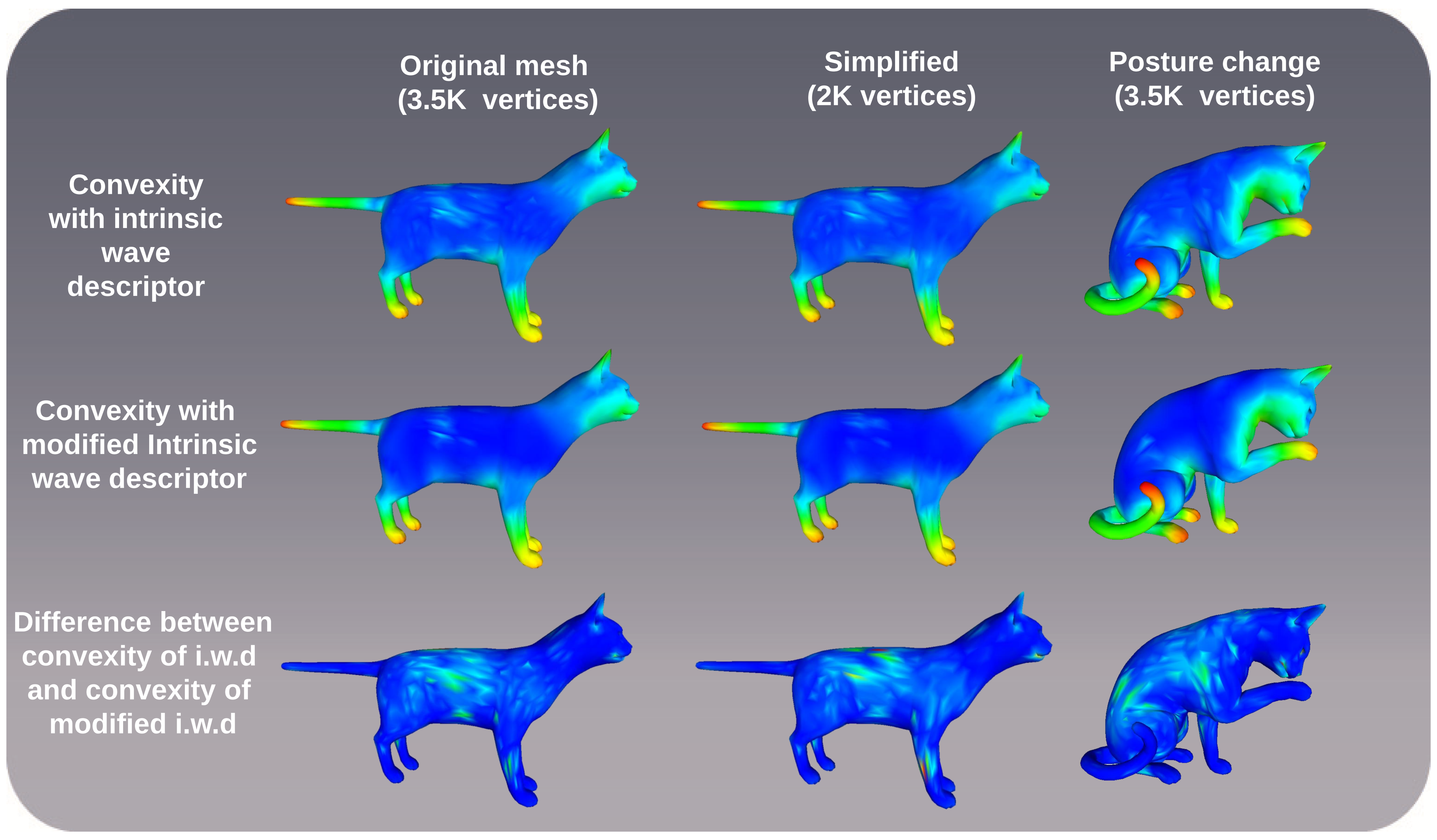


Fig. 2. Convexity color maps computed on original meshes (left), simplified meshes (middle), and deformed meshes (right) by using intrinsic wave desciptors (1st row) and modified ones (2nd row). The difference appears mostly on areas with sliver triangles

II. Minimal Graph Construction

Given a landmark, we build its minimal graph G_M by adding geometric feature points as nodes in an order of proximity until all the following conditions are satisfied:

- The position of the landmark is uniquely defined by its geodesic distances to each node in G_M (Fig. 3)
- The landmark is inside a convex hull of the *N*-gon formed by the nodes (Fig. 4)
- There is no other subgraph on the source which matches to minimal graph

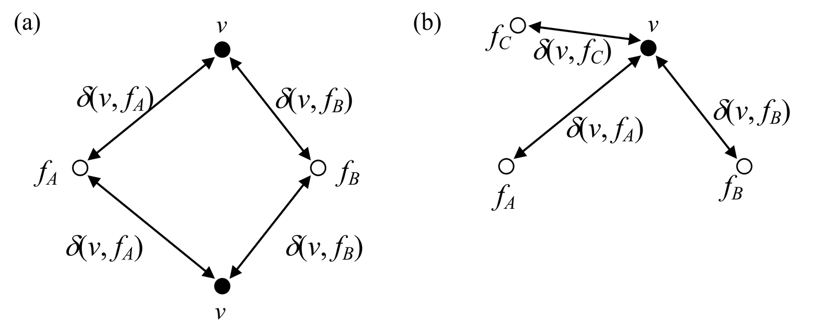


Fig. 3. Construction of the minimal graph. In (a), by using two feature points (white dots), there are two possible position of landmark (black dot), thus the landmark is not uniquely defined. In (b), with a minimal graph composed of three feature points, the landmark position is unique.

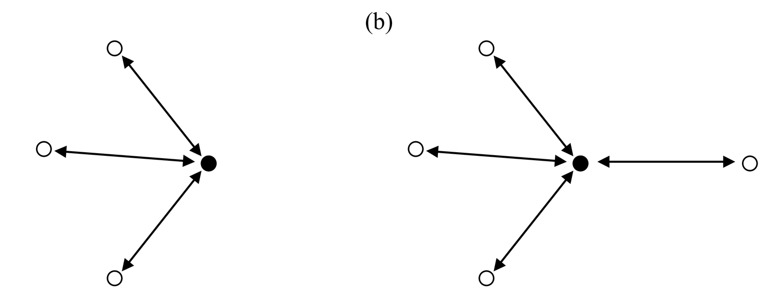


Fig. 4. In (a), the landmark (dark dot) is not surrounded by feature points (white dots). In (b), by adding another feature point, the landmark is surrounded by feature points

III. Graph Matching

- Node labels: convexity values of the feature points
- Edge weights: geodesic distances between feature points
- Enumerate all possible mappings between source and target in spirit to Ullmann's algorithm [2]
- Consider sub-graphs of the source and find an approximate matching (Fig. 5)
- Each mapping is assigned a matching cost defined by the sum of label and weight differences; mappings with smaller costs are considered better

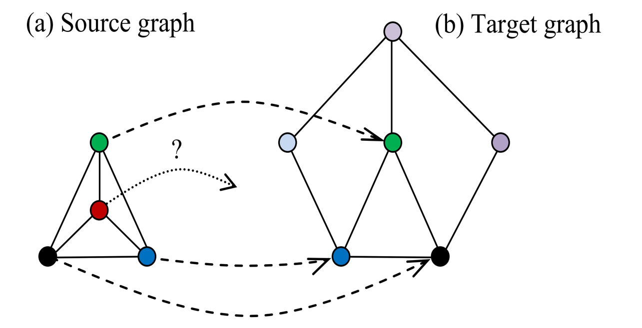


Fig. 5. Vertex in red on the source could not be matched anywhere on the target. Taking into account only subset of the source, we find an approximate matching of the source to the target

IV. Landmark Transfer via Minimal Graph

- Select a set of points on the target with the local shape signatures similar to those from graph G_M. From these feature points we compute the graph G_T by connecting the points which are within the maximum geodesic radius of G_M
- Find matching between G_M and G_T using the graph matching (III)
- Use geodesic distances from graph nodes and surface area to locate the user's landmark (Geodesic distances are not completely reliable to determine the location of transferred landmark Fig. 6)

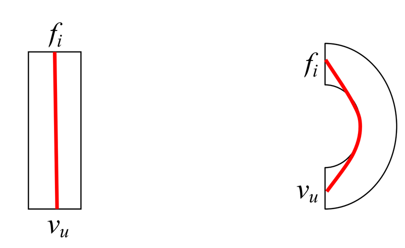


Fig. 6. Geodesic distance between f_i and v_u changes with the mesh deformation. Unlike geodesic path, surface area does not change much under isometric deformation

Let $\{f_i\}$ to be a set of nodes of $G_M=(f_i, l_i)$; $\{f_i'\}$ - the set of nodes of G_T which match to $\{f_i\}$

<u>Def.</u> $A(f_i, l_i)$ is a surface area covered by points within geodesic distance l_i from point f_i

Start from a geometric feature points $\{f_i'\}$ and form a list of all the vertices in an increasing order of geodesic distance l_i' until $A(f_i', l_i')=A(f_i, l_i)$

Distances l_i' are new coordinates to be used to locate the position of transferred landmark on the target

Contributions

- Our method is optimally tailored for transferring landmarks that are presumably sparse, and avoids performing unnecessary full registration
- We improve the intrinsic wave descriptor so as to increase its robustness to topological changes
- Landmark transfer is made more robust, thanks to a newly defined geodesic coordinates that makes use of surface area instead of surface distance

References

[1] A. Tevs, A. Berner, M. Wand, I. Ihrke, H.-P. Seidel, "Intrinsic Shape Matching by Planned Landmark Sampling" , *Eurographics*, 2011
[2] J.R. Ullmann, "An Algorithm for Subgraph Isomorphism", Journal of the Association for Computing Machinery, vol. 23, pp. 31-42, 1976.

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