Title:
Non-Rigid 3D Object Pose Normalization based on Core Segment Symmetrical Features

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Introduction:

Pose normalization is an important preprocessing step in a variety of computer graphics applications. Visualization, broken fragment reconstruction, biometrics and 3D object retrieval are only a few examples of applications that benefit from a pose normalization procedure. Research in pose normalization has given some very efficient methodologies, mainly based on variations of principal component analysis (PCA), like the Continuous PCA and the Normal PCA methods [7, 4]. Another category of methods that effectively deal with the problem is the one exploiting characteristics of symmetry found in a plethora of 3D objects [5]. Pose normalization has mainly focused on rigid 3D objects whereas there has been little research on non-rigid 3D objects. In this paper, we propose a method that achieves pose normalization of non-rigid 3D objects by taking into account the core segment of the object.

Problem statement – Methodology:

Major obstacle in the pose normalization of non-rigid 3D objects is the variety of deformations that they exhibit. More specifically, while most segments of a non-rigid 3D object remain unchanged, deformations occurring in articulating areas and protrusions alter the shape of the objects significantly. The proposed method aims at the extraction of a segment of the 3D object with the minimal deformation which can be used for pose normalization. We have experimentally found that in the majority of non-rigid 3D objects the segment that changes minimally under various deformations and pose change transformations is the *core* segment, or the central partition of the object.

Core Segment Definition

To define the *core* segment of a 3D object, we follow a procedure similar to the one presented in [6]. Initially, each vertex of the 3D mesh is characterized by a conformal factor [1]. The conformal factor φ_i at a vertex v_i of a 3D mesh is the solution to the following discrete linear equation:

$$\varphi_i = \frac{k_i^{\text{targ}} - k_i^{orig}}{L(v_i)} \tag{1}$$

where k_i^{orig} is defined as the discrete Gaussian curvature at vertex v_i of the triangular 3D mesh, k_i^{targ} denotes the uniform Gaussian curvature and $L(v_i)$ denotes the discrete Laplace - Beltrami operator at vertex v_i, with cotangent weights [3].

Using the discrete conformal factors as criterion in a multi-thresholding setting, we partition the surface of the 3D mesh into a set of connected components, thus constructing a graph representation of the 3D object. Using this graph structure, the *core* segment of the 3D object is defined as the connected component that has the least distance from every other connected component of the graph. To perform this ordering, an all-pairs shortest path algorithm is used (see Fig 1).

Fig. 1: Example 3D model with color-coded connected components and the corresponding graph for the same partitioning.

Core Segment Pose Normalization

Once the core segment of the 3D object has been defined, the actual pose normalization is performed. The algorithm is based on the methodology presented in [5].

Initially, the surface of the core segment is projected onto the lateral surface of a cylinder with radius R and height H=2R via rays perpendicular to the axis of the cylinder, emanating from its center towards its lateral surface. The result of the projection is a Normal's Deviation Map (NDM) that stores at each discrete point the difference in angle between the core segment surface point normal and the corresponding normal to the surface of the cylinder.

To achieve alignment between a 3D object and a projection cylinder, we compute two equally weighted factors: (i) a measure of parallelism between the surface of the 3D object and the lateral surface of the cylinder, as given by the mean value of the NDM and (ii) the degree of reflective symmetry established by the NDM:

$$D = \overline{\mathrm{NDM}} + \mathrm{S(NDM)} \tag{2}$$

where $\overline{\mathrm{NDM}}$ stands for the mean value of the NDM and $\mathrm{S(NDM)}$ denotes the reflective symmetry measure of the NDM using a sliding window method, similar to the one proposed in [8].

To this end, based on measure *D*, an octree search strategy is used for the estimation of the optimal rotation in space. The 3D object is rotated accordingly until the optimal rotation which minimizes D and aligns the 3D object's principal axis with the cylinder's axis is found. After the alignment of the 3D object's principal axis, a search on the 3D object's NDM for its secondary principal axes is carried out, based solely on the 3D object's reflective symmetry characteristics.

To test the proposed pose normalization algorithm we used the non-rigid 3D objects from the SHREC'10 *Non-rigid 3D Models* dataset [2]. Our goal is to achieve surface correspondence between the parts of similar 3D objects without taking into account their articulations. Fig. 2 shows example pose normalization results.

Fig. 2: Example pose normalization for objects of the same class. The core segments are shown in red.

Conclusions:

Experiments show that the proposed method can achieve consistent pose normalization regardless the deformation which appears in their protruding parts. This type of pose normalization can be used for efficient visualization of the 3D objects as well as a preprocessing step in a 3D graphics pipeline that requires alignment of the 3D objects, eg. 3D object retrieval.

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