Mesh Construction from Non-Uniformly Distributed and Noisy 3D Points Recovered from Image Sequence

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Abstract

This paper describes a novel method for constructing triangle meshes from noisy and non-uniformly distributed 3D points. It consists of two steps. (1) Noise point removal uses clustering algorithm and epipolar constraint method to identify and remove noise points from the 3D points. (2) Constructive polygonization algorithm interpolates cleaned 3D points to construct a triangle mesh of the object.[1]

1. Introduction

This paper focuses on the construction of object's surface from 3D points. The construction of object surface consists of two steps: Noise Point Removal and Constructive Polygonization. Three significant features distinguish this algorithm from existing methods: (1) It can identify and reconstruct possible surface discontinuities. (2) It can construct a triangle mesh from non-uniformly distributed 3D points. (3) It constructs the mesh by advancing the mesh frontier from smooth surfaces towards surface discontinuities.

2. Noise Point Removal

Two complementary algorithms are devised to identify and remove noise points. The clustering algorithm can identify noise points that arise from incomplete removal of background pixels, while the epipolar constraint method can identify noise points resulting from false matches of 2D features at the feature tracking stage.

An incremental clustering algorithm is used since the number of clusters is not known *a priori*.

A1: Clustering
Form an initial cluster C_0 using a random point.
For each point p,
  Find the nearest cluster C_i to the point p.
  If the distance to $C_i <$ threshold Γ_d,
    group p into C_i.
  Else, create a new cluster C_j with p.

The threshold Γ_d is set dynamically according to the distribution of the 3D points. A cluster C_i is regarded as a noise cluster if the number of points in C_i is smaller than a threshold Γ_n, and the radius r_i of the cluster is much smaller than the distance d_{ij} between C_i and its nearest neighboring cluster C_j, i.e., $r_i/d_{ij} < \Gamma_r$. Both thresholds Γ_d and Γ_r are independent of the sampling rate of the 3D points and can be set to fixed values.

The epipolar constraint states that the projection lines of the corresponding image points must intersect at exactly one point in 3D space: the 3D point that projects to the image points. However, due to limited camera resolution and imperfect camera model, the projection lines do not intersect at exactly one 3D point. A good approximation of the intersection can be obtained by finding the point $\mathbf{Q}$ nearest to the lines [5]. That is, find the $\mathbf{Q}$ that minimizes the mean distance to the lines [6]

$$D = \frac{1}{n}\sum_{i=1}^{n}\left\| (\mathbf{Q}-\mathbf{S}_i) - \frac{(\mathbf{Q}-\mathbf{S}_i)\cdot\mathbf{u}_i}{\|\mathbf{u}_i\|^2}\,\mathbf{u}_i \right\| . \quad (1)$$

where $\mathbf{X} = \mathbf{S}_i + t_i\mathbf{u}_i$ is the equation of projection line i.

If the mean distance D is sufficiently small, then we say that the epipolar constraint is approximately satisfied. Otherwise, the constraint is violated and the 3D point recovered should be regarded as a noise point.

3. Constructive Polygonization

The constructive polygonization algorithm constructs a mesh from the cleaned 3D points. It consists of two main steps: Identifying reliable points and Advancing Mesh Frontier.

The third eigenvalue λ_3 produced by Principal Component Analysis (PCA) can serve as a measure of the ambiguity of a 3D point. A reliable point is identified as a point with a small λ_3 value.

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After identifying reliable points, an initial mesh is first constructed around a randomly chosen reliable point.

A2: Constructing Mesh Around A Point
Given a point p and its neighbors,
  For each reliable neighbor q_i,
    Compute unit direction vector $\mathbf{v}_i$ from p to q_i.
  For each reliable neighbor q_i
  that is not a mesh point of p and
  in decreasing order of distance to p,
    If there is another neighbor q_j such that
    (1) q_j is nearer than q_i is to p and
    (2) q_j lies along a direction close to q_i,
      i.e., $\mathbf{v}_j \cdot \mathbf{v}_i > \Gamma_v$,
    Then, remove q_i from the neighborhood.
  Connect the remaining reliable neighbors to p
  to form a mesh.

Once the initial mesh is constructed, the polygonization algorithm advances the mesh frontier by extending the mesh around the frontier points. Neighbors that are already included in the mesh are never removed. Other neighbors that are not yet included in the mesh, call them *free points*, are chosen for inclusion using algorithm A3.

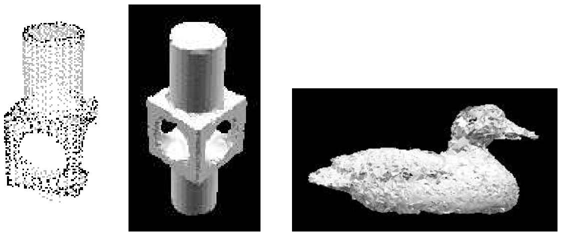
The frontier advancing polygonization algorithm can now be summarized as follows:

A3: Advancing Mesh Frontier
Given a set of free points,
  While there are free reliable points,
    Construct an initial mesh around a
    randomly selected reliable point.
    For each frontier point p,
      Construct the mesh around p.
  For each ambiguous point q, in increasing
  order of ambiguity,
    Construct the mesh around q.
    Mark q as reliable.

4. Test Results and Conclusion

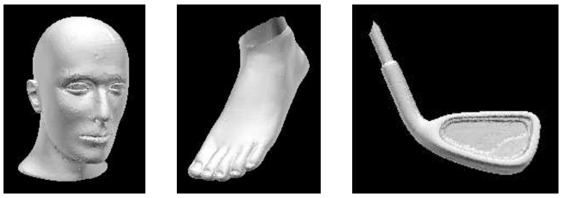
Tests were conducted to verify the performance of the noise removal algorithm and the constructive polygonization algorithm. Test results (Figs. 1 and 2) illustrate that the algorithms for reliable point detection and constructive polygonization (A2, A3) perform well.

In conclusion, this paper presented a method for polygonizing noisy and non-uniformly distributed 3D points recovered from image sequences. The method consists of a noise point removal stage and a constructive polygonization stage. Experimental results show that the method presented in this paper is effective for constructing meshes from noisy and non-uniformly distributed 3D points. Nevertheless, several improvements can be made in the future. First, a mesh smoothing algorithm can be applied to smoothen the surfaces and yet retain the sharpness of the edges and corners. Second, the construction of surface discontinuities can be further improved by considering the normals of the surfaces near possible discontinuities.



(a) (b) (c)

Figure 1. (a) Highly ambiguous points are displayed in black and reliable points in gray. (b) Surface discontinuities of the model are well constructed. (c) Duck model reconstructed from image sequence.



(a) (b) (c)

Figure 2. Polygonization results of standard test data.

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