

A ROBUST MESH-BASED SURFACE INTEGRATION ALGORITHM

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Declaration

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

Saurabh Garg

June 2013

Acknowledgments

Write your acknowledgments here.

Abstract

Surface integration is an important step for automatic 3D reconstruction of real objects. The goal of a surface integration algorithm is to reconstruct a surface from a set of range images registered in a common coordinate system. Based on the surface representation used, existing algorithms can be divided into two categories: volume-based and mesh-based. Volume-based methods have been shown to be robust to scanner noise and small features (regions of high curvature) and can build water tight models of high quality. It is, however, difficult to choose the appropriate voxel size when the input range images have both small features and large registration errors compared to the sampling density of range images. Mesh-based methods are more efficient and need less memory compared to volume-based methods but these methods fail in the presence of small features and are not robust to scanning noise.

This paper presents a robust algorithm for mesh-based surface integration of a set of range images. The algorithm is incremental and operates on a range image and the model reconstructed so far. Our algorithm first, transform the model in the coordinate system of the range image. Then, it finds the regions of model overlapping with the range image. This is done by shooting rays from the scanner, through the vertices in the range image and intersecting them with the model. Finally, the algorithm integrates the overlapping regions by using weighted average of points in the model and the range image. The weights are computed using the scanner uncertainty and helps in reducing the effects of scanning noise. To handle small features robustly the integration of overlapping regions is done by computing the position of vertices in the range image along the scanner's line of sight. Since for every point in a range image there is exactly one depth value, the reconstructed surface in the regions of high curvature will not have self-intersections.

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CHAPTER 1

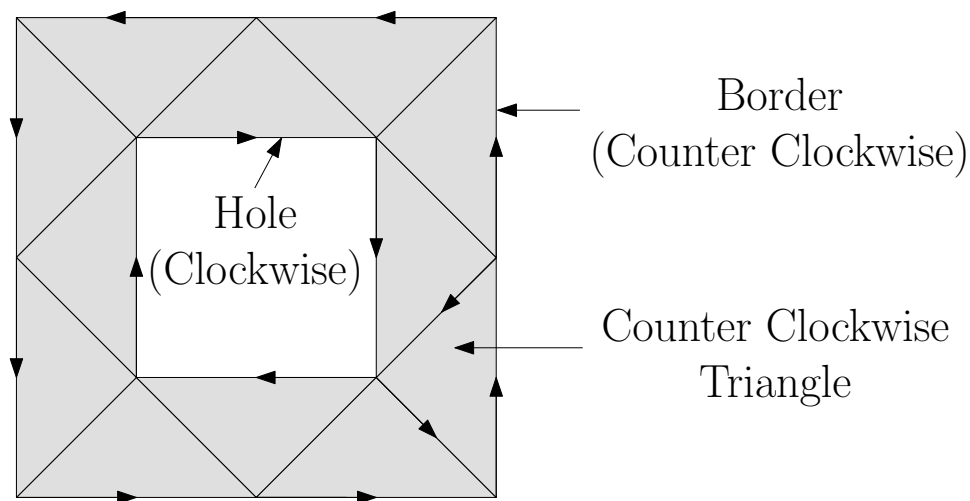
Introduction

Automatic 3D reconstruction of real objects plays an important role in many applications such as animation, virtual reality, and gaming. A widely used approach to reconstruct an object is by using a 3D laser range scanner. Since range scanners have limited field of view, acquisition of 3D geometry of an object requires taking several scans from different viewpoints. The main difficulty with this method is to combine these scans into a unique surface representing the object. This typically involves two steps. First, all the scans must be transformed into the same coordinate system by a process known as surface registration. Second, the registered scans must be integrated into a single model by a process known as surface integration. In this paper we focus on surface integration, assuming the scans have been acquired and registered in a common coordinate system.

1.1 First section

Existing surface integration methods for range images can be classified into two categories: volume-based and mesh-based. Volume-based methods [CVGS05, CL96, Mas02, PDH⁺97, SWI97, SPKA03] convert range images into an intermediate volumetric representation using a signed distance function and extract the final surface using a polygonizing algorithm. These methods can handle objects of arbitrary topology and are considered to be robust with respect to scanning noise, outliers and registration errors. The choice of appropriate voxel size is important for these methods [CVGS05, CL96]. If the voxel size is too large, then features smaller than the voxel size are missed and opposite surfaces of a narrow region will be merged. If the voxel size is too small, then in the presence of scanning noise or registration errors, corresponding surfaces will be reconstructed as separate surfaces. It still remains unanswered as to what extent the signed distance function computed on the discretized space is sensitive to the presence of noisy data. It is also not clear how to choose an appropriate voxel size when the input range images have both small features and registration errors.

Mesh-based methods [Pit96, RST94, SG00, SL92, SL95, SDA00, TL94, ZLL06] directly integrate range images into a single mesh. These methods do not need an intermediate

**Figure 1.1:** Boundary edges.**Table 1.1:** Statistics for the time taken to merge various models

Model	Num. Scans	Input Triangles	Output Triangles	Time Taken (secs)
Drill	14	102284	19152	159
Hello Kitty	9	83627	27856	237
Warrior	10	133927	34613	315
Doll	9	146080	54022	479
Mug	6	114347	68129	613

representation. Hence, they are faster and require less memory compared to volumetric methods. In addition, they are more amenable to data reduction during processing which makes them more feasible for use with very large meshes. Existing methods are, however, sensitive to scanning errors and do not work well on objects with large surface curvature [CL96].

Algorithm 1: Laminar shape generation algorithm for multilobed leaves.

Input : Parameters of the leaf model.
Output: Laminar shape M as a triangle mesh.

```

1   $\{\alpha_i\} \leftarrow \text{GenerateAlphaVeins}(s_0^l, s_0^r, \Delta s)$ 
2   $L \leftarrow \text{GenerateUnilobedLeaf}(\theta(B^l), \theta(B^r), \theta(A^l), \theta(A^r), W^l, W^r)$ 
3  foreach  $\alpha$ -vein  $\alpha_i$  do
4       $L_i \leftarrow L$ 
5       $L_i \leftarrow T_i \cdot L_i$ 
6  end
7  for  $i = 1$  to  $n - 1$  do
8       $p^I(v_i) \leftarrow \text{IntersectLobes}(L_i, L_{i+1})$ 
9       $d(v_i) \leftarrow \frac{d(\alpha_i) + d(\alpha_{i+1})}{2}$ 
10     if  $p(v)$  or  $\theta(v)$  is specified then
11          $p(v_i) \leftarrow p^I(v_i) + p(v)l(\alpha_i)d(v_i)$ 
12     end
13 end
14 for  $i = 1$  to  $n - 1$  do
15     if  $p(v)$  or  $\theta(v)$  is not specified then
16          $M \leftarrow M \cup \{p_j \mid j \in L_i \wedge \text{Index}(q(\alpha_i), L_i) \leq j \leq \text{Index}(p^I(v_i), L_i)\}$ 
17          $M \leftarrow M \cup \{p_j \mid j \in L_{i+1} \wedge \text{Index}(p^I(v_i), L_{i+1}) < j \leq \text{Index}(q(\alpha_{i+1}), L_{i+1})\}$ 
18     else
19          $b_1 \leftarrow \text{FitBSpline}(q(\alpha_i), \theta(q(\alpha_i)), W^l(\alpha_i), r(v_i), \theta(v_i))$ 
20          $b_2 \leftarrow \text{FitBSpline}(r(v_i), \theta(v_i), W^r(\alpha_{i+1}), q(\alpha_{i+1}), \theta(q(\alpha_{i+1})))$ 
21         Discretize  $b_1$  and append the points to  $M$ 
22         Discretize  $b_2$  and append the points to  $M$ 
23     end
24 end

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CHAPTER 2

Chapter 2

2.1 Section 1

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CHAPTER 3

Chapter 3

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CHAPTER 4

Chapter 4

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CHAPTER 5

Chapter 5

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CHAPTER 6

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CHAPTER 7

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References

- [CL96] B. Curless and M. Levoy. A volumetric method for building complex models from range images. In *Proc. of SIGGRAPH*, pages 303–312, 1996.
- [CVGS05] P. Claes, D. Vandermeulen, L. Van Gool, and P. Suetens. Partial surface integration based on variational implicit functions and surfaces for 3d model building. In *Proceedings of 3DIM*, pages 31–38, 2005.
- [Mas02] T. Masuda. Registration and integration of multiple range images by matching signed distance fields for object shape modeling. *Computer Vision and Image Understanding*, 87(1-3):51–65, 2002.
- [PDH⁺97] K. Pulli, T. Duchamp, H. Hoppe, J. A. McDonald, L. G. Shapiro, and W. Stuetzle. Robust meshes from multiple range maps. In *Proceedings of 3DIM*, pages 205–212, 1997.
- [Pit96] R. Pito. Mesh integration based on co-measurements. In *Proceedings on Image Processing, Special Session on Range Image Analysis.*, volume 2, pages 397–400, 1996.
- [RST94] M. Rutishauser, M. Stricker, and M. Trobina. Merging range images of arbitrarily shaped objects. In *Proceedings of Computer Vision and Pattern Recognition*, pages 573–580, 1994.
- [SDA00] Y. Sun, C. Dumont, and M. Abidi. Mesh-based integration of range and color images. In *AeroSense: Aerospace/Defense Sensing and Controls, Sensor Fusion: Architectures, Algorithms, and Applications*, pages 24–28, 2000.
- [SG00] A. D. Sappa and M. A. García. Incremental multiview integration of range images. In *Proceedings of ICPR*, pages 1546–1549, 2000.
- [SL92] M. Soucy and D. Laurendeau. Multi-resolution surface modeling from multiple range views. In *Proceedings of Computer Vision and Pattern Recognition*, pages 348–353, 1992.
- [SL95] M. Soucy and D. Laurendeau. A general surface approach to the integration of a set of range views. *IEEE Trans. on PAMI*, 17(4):344–358, 1995.
- [SPKA03] Y. Sun, J. Paik, A. Koschan, and M. Abidi. Surface modeling using multi-view range and color images. In *Integrated Computer-Aided Engineering*, volume 10:1, pages 37–50, 2003.

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- [SWI97] Y. Sato, M. D. Wheeler, and K. Ikeuchi. Object shape and reflectance modeling from observation. In *Proceedings of SIGGRAPH*, pages 379–387, 1997.
- [TL94] Greg Turk and Marc Levoy. Zippered polygon meshes from range images. In *Proceedings of SIGGRAPH*, pages 311–318, 1994.
- [ZLL06] H. Zhou, Y. Lio, and L. Li. Incremental mesh-based integration of registered range images: Robust to registration error and scanning noise. In *Asian Conference on Computer Vision*, pages 958–968, 2006.