Reconstructing Complex Indoor Environments with Arbitrary Wall Orientations

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Abstract

Reconstructing the architectural shape of interiors is a problem that is gaining increasing attention in the field of computer graphics. Some solutions have been proposed in recent years, but cluttered environments with multiple rooms and non-vertical walls still represent a challenge for state-of-the-art methods. We propose an occlusions-aware pipeline that extends current solutions to work with complex environments with arbitrary wall orientations.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling —Boundary representations; Curve, surface, solid, and object representations.

1. Introduction

With the recent improvements in scanning technology, the demand for automatic pipelines to reconstruct the architectural shape of indoor environments is growing stronger in the architecture and engineering domains. While some buildings exhibit a regular structure and have simple wall arrangements, more complex environments with multiple rooms and arbitrarily oriented walls are more difficult to deal with. Moreover, indoor environments are highly cluttered, which results in large scan occlusions in the corresponding acquired model. Sensor noise and outliers further complicate the reconstruction process.

Existing solutions typically make some assumptions that limit the type of environments handled. A number of recent approaches [MMJ*13, OLA13] assume that the input environments have a 2.5D structure and are therefore not able to capture oblique wall arrangements. Other related methods [vKvLV13, LA13], focused on outdoor building structures, work by computing a feature-sensitive tetrahedralization of the input model, which allows for accurate representation of arbitrary piecewise-planar shapes. However, the final reconstruction is guided by line-of-sight information that is prone to failure when applied to cluttered indoor scenes; moreover, such approaches do not attempt to detect separate sub-environments in the input model.

In this work, we propose an indoor reconstruction method that employs the constrained Delaunay tetrahedralization to faithfully represent the input scene and uses a recursive clustering procedure driven by diffusion distances to segment it into separate rooms. Our envisioned pipeline allows to reconstruct complex environments bounded by non-vertical walls and composed of multiple rooms.

2. Representing the input environment

We assume that our input model consists of a set of 3D point clouds obtained by laser range scanning, with low noise levels but containing scattered outliers and large-scale artifacts originating from glossy surfaces. We also assume that the point clouds have been registered and that they include per-point normal and viewpoint information. The very first step of our pipeline consists in building a 3D spatial representation of the input scene. As we want to model environments with arbitrarily oriented planar walls, we first of all grow planar patches from the input model and build our space partitioning structure directly from them. This differs from the approach of Oesau et al. [OLA13], who detect walls as 2D lines in the vertical projection of the input point cloud.

Since we aim at faithfully representing oblique walls, the 3D Delaunay triangulation used in recent outdoor reconstruction work [vKvLV13,LA13] fits well our purposes. One could compute the intersections between the planes of the detected patches and use them as input points for a tetrahedralization process. However, for cluttered scenes the number of detected patches can be very high, resulting in an extremely high number of intersections and therefore in an unmanageable tetrahedralization. For this reason, we use the *mean-shift* algorithm to cluster the 3D planar patches according to their orientation and offset. We then extract one representative plane for every cluster detected and intersect
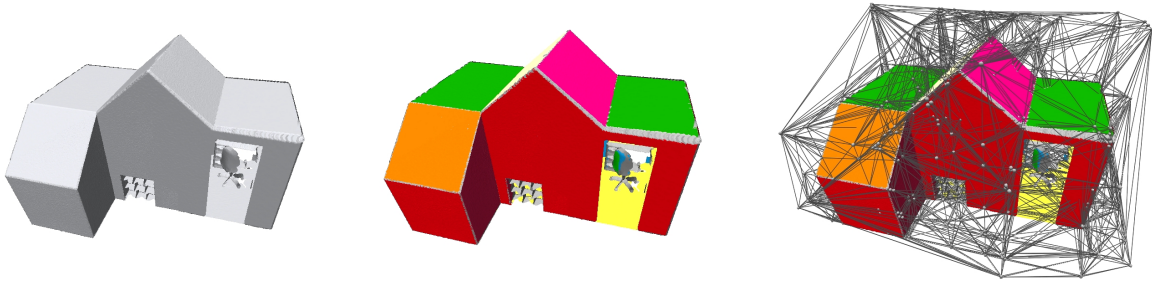
Figure 1: *Construction of the tetrahedral complex. The input model (left) is segmented into planar patches, which are clustered using mean-shift to obtain dominant planes (middle, with colors encoding orientation). The intersections of such planes are used to obtain a 3D Constrained Delaunay tetrahedralization (right, where the gray spheres represent the intersections).*

such planes. From the resulting set of intersections we eventually compute the Delaunay tetrahedralization. Special care has to be taken that the facets of the tetrahedra adhere to the planes obtained from the clustering. Therefore, for each representative plane we consider the intersections it generates and compute their 2D Delaunay triangulation on the plane itself. We set the triangles obtained this way as constraints for the tetrahedralization, thus ensuring that every wall is suitably represented in the complex.

3. Robust volumetric partitioning

Given this tetrahedral representation of the environment, we aim at performing an inside/outside partitioning of its cells. Moreover, we want to cluster the set of inner cells according to the room to which they belong. To do so, we follow the approach of Mura et al. [MMJ*13] and adapt it to work on a tetrahedral cell complex.

We first of all build a diffusion matrix $\mathbf{D}$ representing the dual of the complex. For each pair of tetrahedra (t_i, t_j) in the complex, the corresponding element $\mathbf{D}_{ij}$ of the matrix is defined as follows:

$$\mathbf{D}_{ij} = \begin{cases} e^{-s_{ij}/2\sigma} & \text{if } i \neq j \ \wedge \ t_i, t_j \text{ are adjacent} \\ 1 & \text{if } i = j \\ 0 & \text{otherwise} \end{cases}$$

where σ is a small number and s_{ij} is a measure of dissimilarity between t_i and t_j that corresponds to the likelihood that the facet f_{ij} shared by t_i and t_j belongs to a wall plane. Note that we consider walls to have a thickness, so a wall scanned from two sides generates two distinct wall planes. Two types of information are used to compute s_{ij}. First, we consider the surface of f_{ij} that is covered by a splat-based rasterization of its incident scanned points. We denote this covered surface as $\mathcal{S}_{ij}^{cov}$. Secondly, to account for regions that might be missing because of occlusion, we compute the occluded surface $\mathcal{S}_{ij}^{occl}$ as follows. For every detected planar patch $\mathcal{P}$ we consider the position $vp(\mathcal{P})$ from which it was scanned. We then compute for every $\mathcal{P}$ its projection onto f_{ij} as seen from $vp(\mathcal{P})$. The union of such projections defines $\mathcal{S}_{ij}^{occl}$.

The dissimilarity between t_i and t_j is obtained by combining $\mathcal{S}_{ij}^{cov}$ and $\mathcal{S}_{ij}^{occl}$:

$$s_{ij} = \frac{\text{area}\left(\mathcal{S}_{ij}^{cov} \cup \mathcal{S}_{ij}^{occl}\right)}{\text{area}\left(f_{ij}\right)}$$

This computation can be performed efficiently using the standard rasterization pipeline. In this setting, a per-pixel confidence value can be included in $\mathcal{S}_{ij}^{occl}$ to penalize occlusions originating from patches that are far from f_{ij}.

Applying a diffusion process to this matrix provides global affinity values between all pairs of cells in the complex. This information can be exploited to drive a recursive clustering procedure that yields the final reconstruction, similar to what done by Mura et al. [MMJ*13] for the 2.5D case.

4. Conclusions

We discussed the problem of reconstructing the architectural shape of indoor environments, showing how state-of-the-art techniques can be extended to reconstruct environments with multiple rooms and arbitrary walls orientation. The evaluation of the proposed method is ongoing work. In the future we would like to experiment with the use of other space partitioning schemes, such as BSP-tree representations.

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