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Sketch-based 3-D modeling for piecewise planar objects in single images ☆

Changqing Zou [a,b,c], Xiaojiang Peng [a], Hao Lv [b], Shifeng Chen [b,*], Hongbo Fu [d], Jianzhuang Liu [e,f]

[a] Department of Physics and Electronic Information Science, Hengyang Normal University, Hengyang, China
[b] Shenzhen Key Lab of C.V.P.R., Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, China
[c] Shenzhen College of Advanced Technology, University of Chinese Academy of Sciences, China
[d] City University of Hong Kong, Hong kong
[e] The Chinese University of Hong Kong, Hong Kong
[f] Media Laboratory, Huawei Technologies Co., Ltd., Shenzhen, China

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ABSTRACT

3-D object modeling from single images has many applications in computer graphics and multimedia. Most previous 3-D modeling methods which directly recover 3-D geometry from single images require user interactions during the whole modeling process. In this paper, we propose a semi-automatic 3-D modeling approach to recover accurate 3-D geometry from a single image of a piecewise planar object with less user interaction. Our approach concentrates on these three aspects: (1) requiring rough sketch input only, (2) accurate modeling for a large class of objects, and (3) automatically recovering the invisible part of an object and providing a complete 3-D model. Experimental results on various objects show that the proposed approach provides a good solution to these three problems.

1. Introduction

In recent years, 3-D applications such as 3-D TV and movies, 3-D city, and virtual reality are in rapid development. For these applications, the creation of 3-D models is still one of the main bottlenecks. Generally, tools used to create 3-D models can be classified into two categories: (1) hardware tools (e.g., 3-D cameras) and (2) computer-aided design tools. Compared with the former approach, the latter is less costly and has been extensively studied.

3-D object reconstruction from single images provides a significant interface for a 3-D model design software, which has attracted considerable attention recently, though this topic is challenging due to the ill-posed nature of the problem. In this scenario, intensive interactive 3-D modeling methods [4,7,8,10,13,18,21,22,24,25] have been proposed to reconstruct 3-D objects in single images. In general, some methods where user's interactions are needed throughout the whole modeling process (e.g., [8], and [24]) obtain good modeling results at the cost of intensive user interactions. Some other methods need less user interaction but only focus on reconstructing some special objects or object categories. For instance, the method in [22] reconstructs inflectionally symmetric objects in single images, based on a few user marks which are used to label the symmetric information; the method in [7] assumes that the desired object can be modeled as a polyhedron where the coordinates of the vertices can be expressed as a linear function of a dimension vector. Some other methods achieve efficient 3-D modeling but sacrifice or neglect the accuracies of the results. For example, reconstruction errors might accumulate easily during face-by-face propagation in [18]. The method by Xu et al. [21] only require reconstructed 3-D shapes to be consistent with human perception. 3-D models generated by the 3-sweep technique [4] are only rough approximations of target objects.

In this work, we aim to provide an efficient tools to reconstruct up-to-a-scale piecewise planar objects from single images (for concision, we use “objects” to denote “piecewise planar objects” in the remainder of this paper). In general, there are three main challenges in this topic. The first one is how to provide a rapid modeling of a desired object, i.e., the modeling system must be easy to use for a common user who has less background knowledge. The second one is how to precisely recover a up-to-a-scale 3-D model. The last one is how to obtain a complete 3-D model for an object with invisible parts in an image.

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* Corresponding author.
E-mail address: shifeng.chen@siat.ac.cn (S. Chen).

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To address the above three problems, several previous methods called *semi-automatic* methods, such as [7,10,13,15], first manually obtain the 2-D wireframe of a desired object and then automatically reconstruct the complete 3-D object via recovering the 3-D depths (z coordinates) of the vertices in the corresponding 2-D wireframe. Given a 2-D wireframe of a desired object, the 3-D reconstructions in semi-automatic methods are completely automatic. Therefore, semi-automatic methods greatly simplify the work of the users, compared to those methods where user interactions are needed throughout the whole modeling process. However, there are still several disadvantages for these methods. Firstly, drawing a complete and precise 2-D wireframe of an object is not very tractable and takes time; secondly, the positions of the invisible vertices drawn by the user are imperfect in terms of precision, and they are treated as constants, i.e., the 2-D positions of the invisible vertices are fixed during the reconstruction, which results in a consequent deterioration in reconstruction quality.

We propose a sketch-based 3-D modeling approach to address all these three problems in a unified framework. The pipeline of our method is shown in Fig. 1. Given an input image, the user first roughly sketches the visible vertices and edges of an object of interest. Based on the manually drawn sketch and the edge information from a line segment detector, the system first generates an initial 2-D wireframe of the visible part of the desired object (Section 2). Then an optimization algorithm is proposed to reconstruct the precise 3-D wireframe of the visible part (see Section 3). Further, the invisible part of the object is automatically recovered based on the 3-D structure of the visible part (Section 4).

Our approach also bears close resemblance to the previous semi-automatic methods in [7,10,13,15], but is advantageous in two aspects. First, in terms of the efficiency of user interface, our method automatically derives initial 2-D wireframes from the input users' sketches and detected line segments. Therefore, it is more convenient to use and lessens the user interactions. Second, in terms of the reconstruction accuracy, the good performance of the proposed method mainly comes from two facts:

(i) the 2-D positions of the vertices in the 2-D wireframe whose precise locations are uncertain are treated as variables, and they are jointly optimized together with the depths of all the visible vertices during the 3-D reconstruction of the visible part. Therefore, our approach can reconstruct a more precise 3-D visible part than those reconstructing the 3-D visible part from an inaccuracy 2-D wireframe where the x- and y-coordinates of all the vertices are fixed;
(ii) after the invisible topological structure is obtained, the 3-D positions of the invisible vertices can usually be computed based on the recovered 3-D visible part directly. Therefore, our method usually produces a more precise 3-D invisible part than previous methods.

The rest of this paper is organized as follows: Section 2 details how to generate an initial 2-D wireframe W_{2di} based on users' sketches. Sections 3 and 4 present the algorithms which reconstruct the visible part M_{v3dw} and the invisible part M_{h3dw} of a desired object, respectively. Section 5 gives the experimental results and some discussions.

2. Generation of initial 2-D wireframe

2.1. User's sketches and the initial 2-D wireframe

We require the user to provide three types of interaction information (as shown in Fig. 2) to generate the initial 2-D wireframe W_{2di}. The first type includes (approximately) closed contours, we call them *sketch vertices*. These sketch vertices encircle the possible locations of the visible vertices, and are drawn by the user with one stroke. The second type consists of the lines connecting two sketch vertices, called *sketch lines*, which are used to represent the connectivity of the vertices. The last type includes the artificial lines used to indicate the coplanar relationship of two sketch lines (it can be extended to cover more geometrical relationship). Note that the artificial lines are not the components of the 2-D wireframe. The sketch vertices and sketch lines are automatically recognized from the following criteria:

(i) (approximately) closed contours finished by one stroke are treated as sketch vertices;

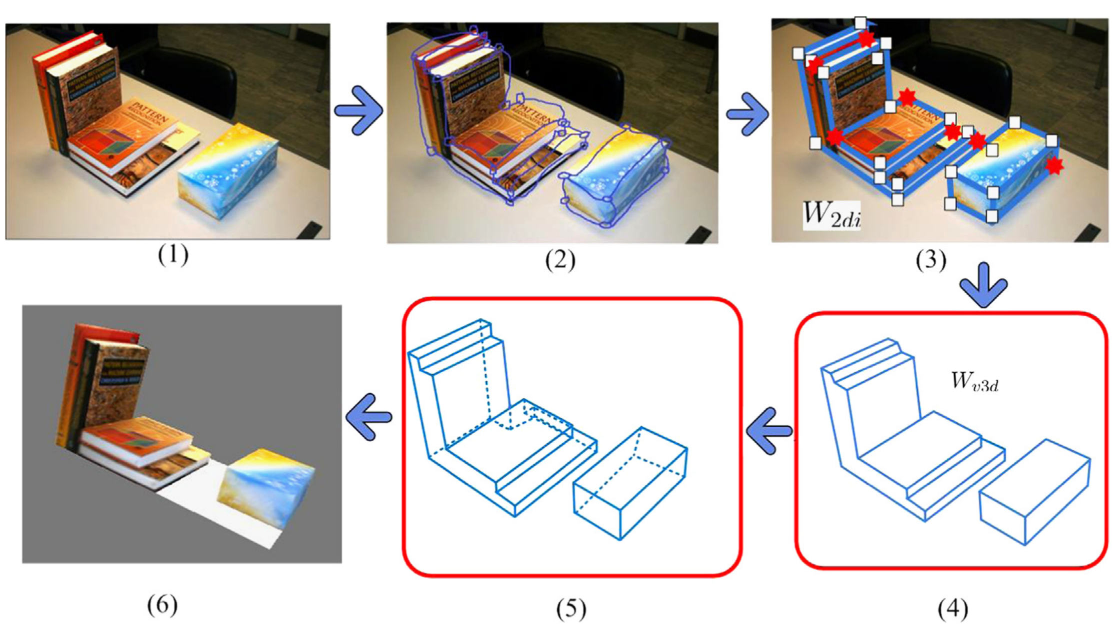

Fig. 1. Flow chart of the proposed approach. (1) The original image. (2) Roughly sketched vertices and edges for the visible part of the desired object. (3) Automatically generated 2-D initial wireframe W_{2di}. Note that some vertices in W_{2di} have no precise locations, which are highlighted with red stars. (4) Precise reconstruction of 3-D wireframe M_{v3dw} from W_{2di}. (5) Inference of the invisible 3-D geometries (marked with dotted lines). (6) Complete 3-D objects. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)