Pattern Recognition 60 (2016) 543–553

Contents lists available at ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/pr

An example-based approach to 3D man-made object reconstruction from line drawings

Changqing Zou [a,b], Tianfan Xue [c], Xiaojiang Peng [a], Honghua Li [d], Baochang Zhang [e,*], Ping Tan [b], Jianzhuang Liu [f]

[a] Hengyang Normal University, China
[b] Simon Fraser University, Canada
[c] Massachusetts Institute of Technology, United States
[d] Shandong University, China
[e] School of Automation Science and Electrical Engineering, Beihang University, Beijing, China
[f] Huawei Technology Co. Ltd., China

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form
27 May 2016
Accepted 28 May 2016
Available online 11 June 2016

Keywords:
3D reconstruction
Example-based
Line drawing
Probabilistic graphical model

ABSTRACT

3D reconstruction from a single 2D line drawing is an important but challenging problem in computer vision. Existed methods usually fail when line drawings contain large degree of noise named sketch errors. In this paper, we present an example-based approach to reconstructing 3D object, either planar or curved, from a single-view line drawing with sketch errors. Our method is to first decompose the input line drawing into primitive components and cluster them into local groups, then turn each group into 3D shapes via a novel example-based algorithm, and lastly integrate those recovered 3D shapes from all groups to build a final complete 3D model. Comprehensive experiments on a wide range of line drawings depicting man-made objects show that the proposed approach outperform previous work, especially for line drawings containing large degree of sketch errors.

1. Introduction

Line drawing is one of the simplest and most direct means to illustrate 3D objects. The human vision system is able to interpret 2D line drawings as 3D objects without endeavor. The emulation of this ability is an important and long-standing research topic in computer vision and graphics. Three dimensional reconstruction from 2D line drawings benefits various applications such as reconstruction from conceptual sketches [1–4], interactive 3D modeling from single images [5–7], and sketch-based 3D shape retrieval [8–10].

The problem of 3D reconstruction from single 2D line drawing is challenging since it is intrinsically ill-posed due to the missing of the depth information. In order to resolve the ambiguity, some researchers use additional information such as local regularity cues, reference models, and gestures [11–16]. Differently, the rule-based methods [1,17–23] usually reconstruct 3D objects by optimizing an objective function built from a set of heuristic image-based rules that summarize human visual perceptions. Generally, rule-based methods can success for a large range of line drawings, but might fail to obtain "good" results, e.g., vertices on a planar face might not exactly lie on the same plane in the result model. This is mainly due to the fact that heuristic rules cannot cover all cases [24,25]. Imperfect line drawings and sketch errors also make those rules to be less useful. Moreover, there is no principled way to tune the parameters that balance each type of heuristic rules.

In this paper, we propose an example-based 3D reconstruction approach, which is the comprehensive version of our preliminary work published in [24]. We extend the previous algorithm to handle wider range of 3D man-made objects, which are composed of both planar and/or curved surfaces. Comprehensive experiments are performed to evaluate the algorithm's performance on line drawings consisting of both straight and curved segments. The key insight of the proposed approach is that a complex 3D object, especially a man-made object, can usually be decomposed into a set of simpler primitive 3D shapes. For instance, the mechanical object in Fig. 1(a) is a composition of 3D shapes shown in Fig. 1(c), which can be generated from the six 3D parametric templates shown in Fig. 1(d). This insight motivates us to adopt an example-driven approach to reconstruct 3D objects from line drawings.

Given a line drawing with both straight and curved lines, our method reconstructs the 3D object in four steps: (1) decompose the input line drawing into simple components, (2) group these components into part groups based on a set of structure

* Corresponding author.
E-mail address: bczhang@buaa.edu.cn (B. Zhang).

http://dx.doi.org/10.1016/j.patcog.2016.05.031
0031-3203/

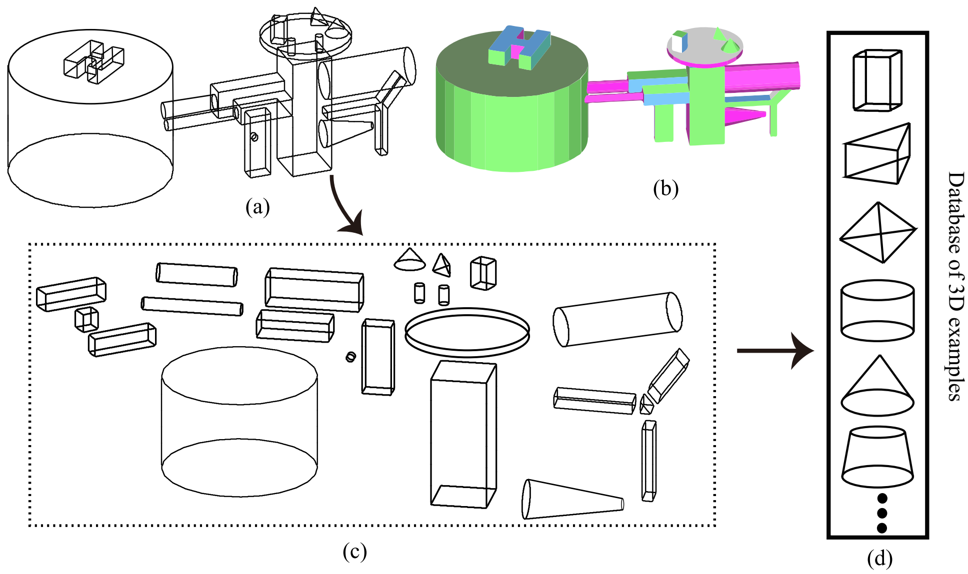

Fig. 1. Illustration of example-based 3D reconstruction from single line drawing. The input 2D line drawing (a) is decomposed into a set of simpler components (c), each of which can be reconstructed by fitting parametric templates from a database (d). These recovered 3D shapes are finally integrated to form the complete 3D model (b).

constraints, (3) reconstruct the 3D geometry for each part group using a novel example-based reconstruction algorithm, and (4) integrate obtained 3D shapes into a final complete 3D object. The core component of the proposed approach is the example-based 3D reconstruction algorithm, where the reconstruction problem is solved with a probabilistic graphical model. The proposed framework is flexible to exploit other reconstruction algorithms (e.g., rule-base approaches) if our example-based algorithm fails to produce satisfactory results.

Our most prominent advantage over previous rule-based methods is the robustness to sketch errors. The ruled-based methods tend to fail to reconstruct plausible 3D geometries from imperfect line drawings, because these rules only based on local information of line drawings and sketch errors may easily violate their assumptions. In the contrary, the proposed method does not directly reconstruct 3D geometry of a line drawing with sketch errors. Instead, we reconstruct 3D geometries by exploiting the most plausible 3D examples (templates) that correspond to the line drawing from the database with a global optimization strategy. Naturally, the proposed approach is more robust than previous rule-based methods.

2. Related work

Here we generally discuss works related to computational interpretation of line drawings, rule-based 3D reconstruction, and 3D reconstruction of curved objects.

Computational interpretation of line drawings: This topic has spanned more than four decades. Generally, existed work can be roughly classified into three categories: (1) line labeling, (2) linear programming based reconstruction, and (3) optimization-based (rule-based) reconstruction. Interested readers may refer to [26–28] for insightful surveys on earlier researches.

Line labeling focuses on finding a set of consistent labels from a line drawing to test the correctness and/or realizability of the line drawing [4,29], but it does not explicitly recover 3D objects. The methods based on *linear programming* [30,31] reconstruct 3D models by solving a linear system which is built from a set of geometrical conditions that the model must fit. In general, linear programming has difficulty to tolerate sketching errors that often exist in a line drawing. Modern methods of 3D reconstruction from line drawings are often *optimization-based*, which usually determine the 3D geometry of a line drawing from the solution that optimizes a certain objective function. Most previous optimization-based 3D reconstruction methods [1,17–19,21,23,32] only focus on planar objects. Being different from those methods mentioned above, the proposed method in the work is a temptation to infer plausible 3D objects, either planar or curved, from single line drawings using a data-driven solution.

Rule-based 3D reconstruction: Rule/regularity based algorithms [7,33–35] are extensively used to reconstruct 3D objects or scenes from single images. A recent survey [36] can be referred to explore that direction. Here, we only discuss algorithms with single drawing as input.

The recent advances [18,19,23] can reconstruct more complex objects than previous works. Ref. [18] finds desired objects in search space of much lower dimensions. This method works well on complex line drawings with low degree of reconstruction freedom (DRF), but increased DRF would make it less robust. Refs. [19,23,37] tried to solve the hard optimization problem caused by the dimensional disaster of a complex line drawing using a divided-and-conquer strategy: first decompose the complex line drawing into a set of parts, then reconstruct 3D shapes from these parts with a rule-based algorithm, finally merge these 3D shapes together to generate the final 3D object.

Our proposed method also utilizes a divided-and-conquer strategy with individual parts reconstructed using example-based algorithm. The example 3D shapes serve as template with internal configurations, which usually lead to better results from line drawings with sketch errors than rule-based algorithms. Most rule-based 3D reconstruction methods assume that the faces are given before the 3D reconstruction. In fact the face identification problem is not trivial [38]. Without such assumption the proposed example-based algorithm infers candidate 3D examples from a pre-defined database, which avoids failure cases caused by unsuccessful face identification.

3D reconstruction of curved objects: Recent research on this topic are mainly rule based on [1,16,22,39]. Lipson and Shpitalni in [1] solved the problem of reconstructing cylindricality by three steps: first approximate a cylindrical face with a set of rectangular faces; then reconstruct 3D geometry of rectangular faces using a rule-based algorithm; finally fit curved faces to these rectangular faces. Wang et al. [22] extended the idea in [1] to reconstruct more