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Least-squares 3D reconstruction from one or more views and geometric clues ☆

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Abstract

We present a method to reconstruct from one or more images a scene that is rich in planes, alignments, symmetries, orthogonalities, and other forms of geometrical regularity. Given image points of interest and some geometric information, the method recovers least-squares estimates of the 3D points, camera position(s), orientation(s), and eventually calibration(s). Our contributions lie (i) in a novel way of exploiting some types of symmetry and of geometric regularity, (ii) in treating indifferently one or more images, (iii) in a geometric test that indicates whether the input data uniquely defines a reconstruction, and (iv) a parameterization method for collections of 3D points subject to geometric constraints. Moreover, the reconstruction algorithm lends itself to sensitivity analysis. The method is benchmarked on synthetic data and its effectiveness is shown on real-world data.

Keywords: Single-view 3D reconstruction; Unicity of reconstruction; Least-squares estimation; Performance analysis

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1. Introduction

This article addresses the problem of 3D reconstruction of scenes that display properties of planarity, orthogonality, parallelism, and symmetry, such as the man-made scenes in Fig. 1. This problem is of interest for archeology, urbanism, architecture, virtual reality, reverse engineering, etc.

Knowing geometric properties of the scene allows to perform 3D reconstruction in situations that general methods [31] cannot treat. For example, a reconstruction may be obtained from a single image [10,28,38,43] or from multiple views with too few point correspondence.

1.1. Current approaches

Methods for 3D reconstruction from image points and geometric clues can be roughly classified as ‘‘model-based’’ and ‘‘constraint-based.’’ The former reconstruct assemblages of primitive shapes, such as parallelepipeds, prisms, cylinders, while the latter exploit geometric properties of the scene-planarity, orthogonality, etc.

In *model-based methods* [11,26,29], the scene is defined as in CAD [45] systems. For example, the buildings in Fig. 1 can be decomposed in parallelepipeds, prisms, and truncated pyramids. By fitting the model to image data, its dimensions, position, and orientation are determined. The fact that the scene must be decomposable in primitive shapes is the main limitation of model-based methods.

In *constraint-based methods*, this limitation does not exist, as any shape can be reconstructed as long as there are enough geometric properties to define a unique reconstruction. Geometric properties are either detected automatically [5,12,13,50] or, as in the present work, given by the user [1,2,10,38,43]. Some forms of symmetry have been exploited [24,37,49] and, in theory, general polynomial constraints on the

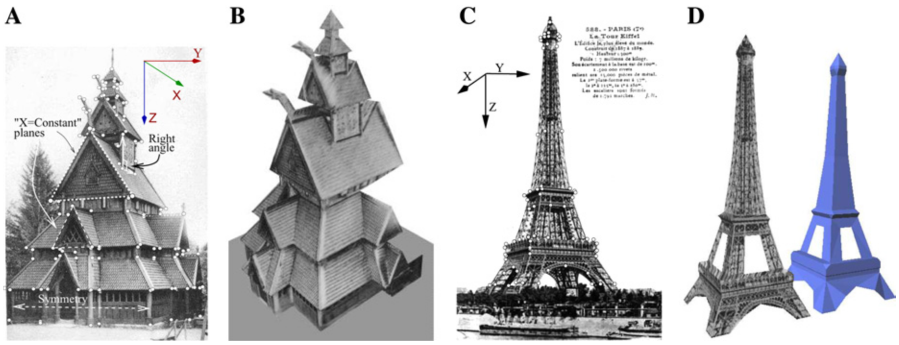

Fig. 1. (A) A man-made scenes, rich in planarities, parallelisms, orthogonalities, and symmetry: the outlined triangles lie on vertical planes, there are many horizontal planes and there is an approximate symmetry with respect to a vertical ‘‘*X*–*Z*’’ plane. (B) This reconstruction is obtained by using the 2D points (white dots) in the left image at left and some geometric information known à-priori. The 3D points (white dots at left) are estimated and visualized with textured planar surfaces. (C) A man-made object, rich in symmetry. (D) Reconstruction, with and without texture.