3D Reconstruction of Architectural Objects from Photos

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Abstract

An algorithm of the 3D reconstruction is based on model to image correspondence, which gives possibility to use constraints of a model for calculation of camera and model parameters.

Models are assembled from simple ready parametric blocks by modeler. Each block is composed from convex plane faces, described in text form. Blocks are mutually arranged, aligned and constrained to minimize the number of total parameters of a model.

Some edges of an object are marked on the images by line segments and on the model simply by pointing them. Procedure of reconstruction minimizes the sum of distances between marked and projected edges on images by variation of model and camera parameters. If input information is sufficient, camera position and orientation with respect to the model, its focal length, and exact dimensions of the model are calculated.

Received in such a way model of an object and camera parameters for each image provide the basis for subsequent operations: textures assignment, lighting conditions reconstruction. Finally the model can be exported to external 3D data formats.

Keywords: *Photogrammetry, 3D reconstruction, Modeler, Photomontage, Texture, VRML..*

1. INTRODUCTION

3D reconstruction of architectural objects from photos allows to restore external look of existing buildings in 3D form. Interiors can be reconstructed as well. Rough reconstruction of the main volumes is sufficient, details of architecture can be expressed through texture images. Original images are used as a source for plane texture images. In the case of perspective textures original images are used as is. Town scenes consisting from many buildings can be composed later from separately reconstructed objects, by means of similar reconstruction of separate objects position and scale.

Such scenes are ready for visualization by 3D engines without any additional illumination, because textures are already illuminated.

Realistic photomontage can be performed on the base of original image and 3D model of some object to be mounted to the photo. Special algorithm of ray-tracing allows to perform photomontage with correct shadows and reflections.

Currently there are two different approaches to 3D reconstruction from photos.

One is based on image-to-image correspondence. Separate points are marked on at least two images and their 3D coordinates and camera parameters are reconstructed using classic photogrammetry approach. Then edges and polygons can be build using these points, as it is done in Photomodeler [1], or parametric blocks can be reconstructed using known 3D coordinates of the vertices, as it was done in Renoir 3.10 [2, 3].

Another approach is based on model-to-image correspondence [4]. Parametric model of an object is created. Then parameters of a model and camera are optimized to provide the best fitting of an image and projection of a model on image plane through camera. This approach provides much more precision of reconstruction, because constraints, implied by model on vertices coordinates are used during reconstruction procedure.

2. MODELER

Models are assembled from simple ready parametric blocks by modeler. Prototypes of the blocks are described in special textual files. Each block is composed from convex plane faces. Coordinates of vertices are linearly expressed through internal parameters of the block.

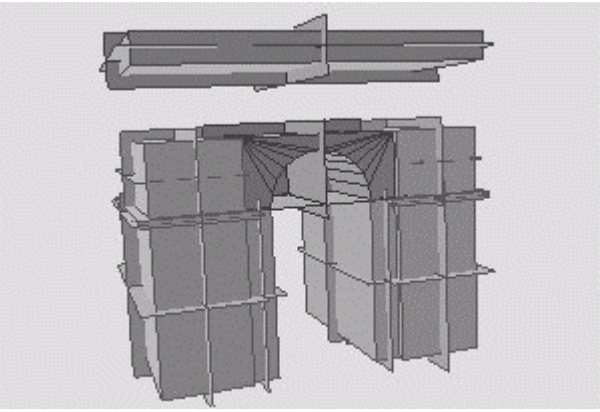

Figure 1: Creation of a model from the blocks

Blocks are mutually arranged, aligned and constrained to minimize the total number of model parameters. It is performed by pointing coplanar or parallel faces, collinear or parallel edges, if any. Besides external faces and edges axial planes and edges can be used for alignment. Parameters of the blocks can be constrained if some block dimensions are equal or proportional.

Internal parameters of all blocks and position and orientation of the same blocks constitute the initial set of model parameters. Block parameters are expressed through model parameters. The number of model parameters is reduced during the procedure of blocks alignment and edges lengths equation.

Mutual alignment of the blocks creates hierarchical structure of the model. First alignment of the current block to any other block defines parent-child relation. Further alignments of the child block can be performed only to the same parent. Transformation of block CS to absolute CS is calculated over the tree of parent - child relations.

Alignment of blocks by any faces and edges makes transformation of block CS with respect to parent block CS dependent on internal parameters of both blocks. Both position and orientation of the block depend on internal parameters of the blocks. CS shifts are found by solving 3 planes intersection equations. Because besides of the value of coordinates transformations and vertices coordinates, gradients and hessian of these values from all model parameters should be calculated - proper calculations become too complicated, time and memory consuming.

More easy calculations can be provided, if blocks are aligned by bounding boxes only. Possibly, it is sufficient for creation of architectural models, but surely provides less possibilities.

3. RECONSTRUCTION

The goal of reconstruction - to recover actual dimensions of an object and camera attitude with respect to an object. Created model has very approximate similarity with an object. Corresponding edges should be marked on images and on a model of an object.

Arbitrary part of an edge can be marked - marked segment is matched with projected edge line. Then reconstruction procedure performs optimization of a model and camera parameters to provide the best fitting of model edges projected on image plane with corresponding segments marked on images.

Distance between marked segment and projected edge line is calculated on the base of current model and camera parameters and such distances are summed for all marked images. Besides the value of distance - gradient and hessian from all parameters of the model and proper camera are calculated. They are used for calculation of the next increment of all pointed parameters. Combination of the method of steepest descent and of Newton method is used for minimization of target function. Special measures are taken to provide optimization of detectable parameters only. Parameters with 0 value of gradient and of proper row of hessian matrix are excluded in advance. If some parameters increment can't be deduced during solving the system of linear equations - it is set to 0 and calculation is continued for the rest of parameters.

Initial guess for model and camera parameters should be found before final optimization of parameters. It is found separately for position and orientation parameters, using the algorithms, described in [1]. Although these algorithms provide fast calculation of initial guess for camera orientation - proper solution depends itself on used initial guess, so some set of possible orientations should be checked.

Auto-edge detection procedure is used for marking object edges on photos. This procedure finds exact position of a segment on image around manually marked edge.

4. TEXTURING A MODEL

It is possible to assign a color texture, taken directly from images, to object faces. Textures can be assigned automatically - by selection an image with the best visibility, or manually - by picking proper face on a desired image. Perspective texture mapping is used for internal visualization of a model - image is transformed from the real camera view to the current view of the model. Color of the face is calculated as the mean color of the face texture pixels.

Figure 2: Textured model

5. PHOTOMONTAGE

Photomontage is performed on the base of available photo-image, which should be modified by placement of additional objects. Photomontage scene consists at least from ground plate, where some 3D model will be placed,

and from background image. In some cases, rough reconstruction of some objects from source image should be performed, if shadows and reflections between them and inserted objects are expected, or for retrieval of camera parameters. Placement of 3D objects (cars, for example) and rendering of images can be performed by usage of INSPIRER, where special mode of ray-tracing for photomontage scenes is provided.

Background pixels are drawn as is. Pixels, corresponding to reconstructed objects are modified: brightness depends on ratio of total and direct illumination of proper point on the scene. Thus, correct shadows and reflections are provided for source image pixels. Mounted 3D object is rendered as usually, background image and reconstructed objects are reflected by specular surfaces.

Figure 3: Photomontage of a car

6. EXAMPLE OF RECONSTRUCTION

Model of the Cathedral of the Savior consists from 1053 blocks, it has 6478 original parameters which are reduced to 93 free parameters. Model has a lot of symmetric parts, which were created by copying of the whole branches of blocks. Image on the figure below is rendered by Inspirer without textures.

Figure 4: Cathedral of the Savior, Moscow

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] PhotoModeler, Eos Systems Inc., Vancouver, BC, Canada, V6J2, 1994.

[2] Barladian, B.N., Kugushev, E.I., and Zueva, E.Yu. Scene Reconstruction from Multiple Photos with Aid of Parametric 3D Models, *5th Int. Conf. Of Computer Graphics and Visualization in Russia, Proc., St. Petersburg, 1995, vol. 1, pp. 190-192.*

[3] Kargashin, A. Yu., Kugushev, E.I., and Starostin, E.I. *Two-Stage Multiple Cameras Calibration, 5th Int. Conf. Of Computer Graphics and Visualization in Russia, Proc., St. Petersburg, 1995, vol. 1, pp. 214-216.*

[4] Paul E. Debevec, Camillo J. Taylor, and Jitendra Malik. *Modeling and Rendering Architecture from Photographs. In SIGGRAPH '96, August 1996...*

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