A FLEXIBLE APPROACH TO 3D RECONSTRUCTION FROM SINGLE IMAGES

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Traditional image-based 3D reconstruction methods use multiple images to extract 3D geometry. However, it is not always possible to obtain such images, for example when reconstructing destroyed structures using existing photographs or paintings with proper perspective (figure 1), and reconstructing objects without actually visiting the site using images from the web or postcards (figure 2). Even when multiple images are possible, parts of the scene appear in only one image due to occlusions and/or lack of features to match between images. Methods for 3D reconstruction from a single image do exist (e.g. [1] and [2]). We present a new method that is more accurate and more flexible so that it can model a wider variety of sites and structures than existing methods. Using this approach, we reconstructed in 3D many destroyed structures using old photographs and paintings. Sites all over the world have been reconstructed from tourist pictures, web pages, and postcards.

The approach does not need models of the objects nor known internal camera calibration [1]. It also does not use vanishing lines or vanishing points [2], which may be unavailable or hard to extract. We use several types of constraints: point/coordinate constraints, surface constraints, and topological constraints. We solve first for camera internal and external parameters using one set of constraints then use additional constraints to obtain 3D coordinates for reconstruction. The camera parameters and 3D coordinates are computed from photogrammetric bundle adjustment: a simultaneous triangulation of all data. Each point p, extracted from an image i, has two image coordinates, x_p and y_p and contributes two equations (representing the condition that the projection center, image point, and object point all fall on a straight line):

$$x_p = F_x(f_o, x_o, y_o, X_p, Y_p, Z_p, X_i, Y_i, Z_i, pitch_i, yaw_i, roll_i);$$
$$y_p = F_y(f_o, x_o, y_o, X_p, Y_p, Z_p, X_i, Y_i, Z_i, pitch_i, yaw_i, roll_i). \quad (1)$$

The parameters are the internal camera parameters (focal length f_o, and principal point x_p, y_p), 3D object coordinates of point p (X_p, Y_p, Z_p) and the camera position and orientation. Those six camera parameters are the same for all points measured in the same image, however each point adds three unknown XYZ coordinates. The image coordinates x_p and y_p may include parameters for distortion. In the calibration phase, certain constraints are used. Points with same X coordinates, points with same Y coordinates, points with same Z coordinates, one point with zero coordinates to define the origin of the object coordinate system, and one point with a zero Y and Z to define the orientation. Arbitrary distance is assigned between two points to define an arbitrary scale. When sufficient constraint equations are combined with equations (1), solution of the internal and external camera parameters is possible. In the reconstruction phase, more constraints are combined with equations (1). Those include shapes such as planes, cylinders, quadrics, spheres, and circles in addition to topological relationships such as perpendicularity, parallelism, and symmetry.

References

[1] P.E. Debevec, C.J. Taylor, J. Malik, "Modeling and rendering architecture from photographs: A hybrid geometry and image-based approach", *SIGGRAPH'96*, pp.11–20.
[2] A. Criminisi, A. Zisserman, A., "Single view metrology", *I.JCV2000*, 40(2), pp. 123-148.

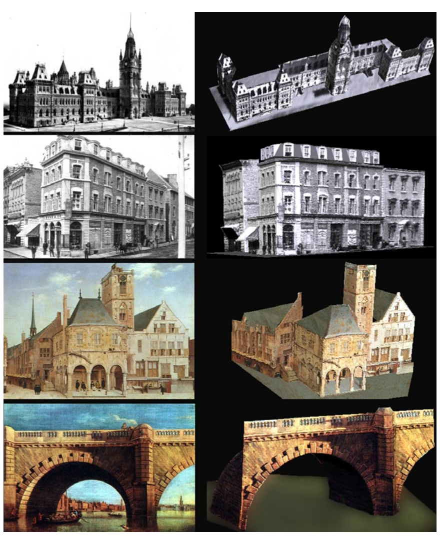

Figure 1: 3D Reconstruction from Old photos and paintings.

Figure 2: Examples of 3D reconstruction from tourist pictures.