CS664 Lecture #13

Camera calibration,multi-camera shape extraction and optical flow 10/18/01

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1 Camera Calibration

The camera calibration problem involves determining extrinsic and intrinsic parameters of a camera. The external(extrinsic parameters) of a camera include position coordinates (X, Y, Z), orientation parameters $(pitch, roll, yaw)$. The internal(intrinsic parameters) of a camera include focal length and lens distortion parameters. Besides the above parameters, resolution and size of the CCD array (format) are additional important parameters that can be evaluated during the calibration process.

The camera calibration procedure involves the following steps:

a. Capturing stero-pair images of a target area/object using two cameras (left and right (L and R) images as shown in Figure 1)

b. Extracting and identifying corresponding(conjugate) points on left and right image (points like A and B in Figure 1 of a certain calibration pattern)

c. Solve for the unknown parameters (intrinsic and extrinsic parameters of the camera) using adjustment (least square or least median square) techniques

2 Shape extraction using multiple cameras

A multiple cameras configuration can be used for shape reconstruction. Cameras will be oriented in different directions focusing at the object of interest and the images will be analyzed to reconstruct the object's shape (example configuration see Figure 2). Most popular multiple camera shape reconstruction techniques are explained below.

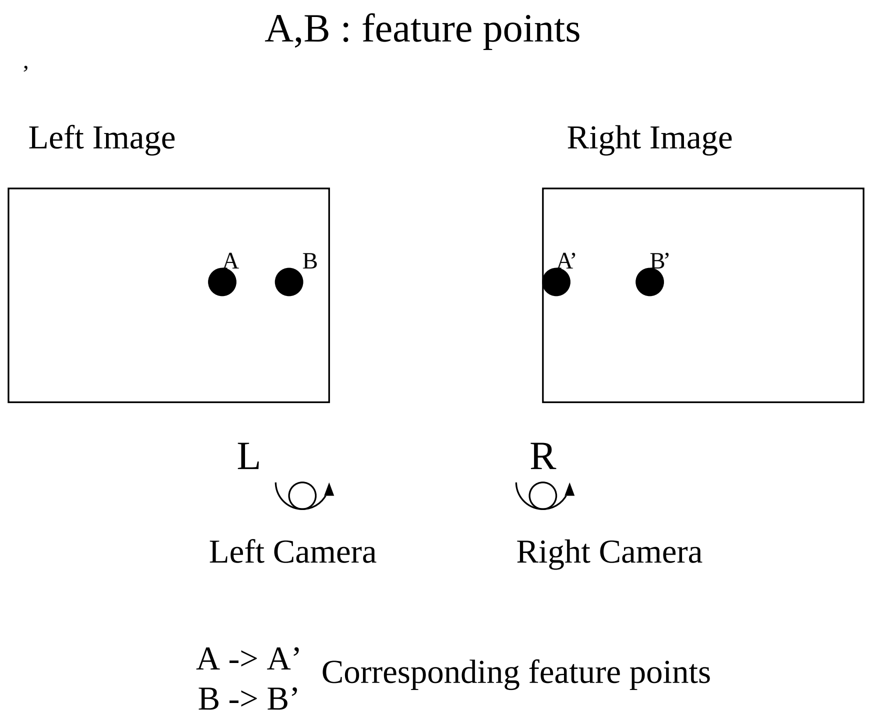

Figure 1: Stereo image acquisition for camera calibration

2.1 Reconstruction from Silhouettes

This involves back projecting each silhouette in the multiple camera and estimating the intersection volume. The problem with this method is reconstruction of scenes with indentations. The reconstruction techniques wont be able to capture indentation characteristics of a shape(see Figure 3). Therefore the reconstructed volume that we will be getting from this construction only shows the convex hall or visual hall of the shape.

Canonical operations could be used as a post processing procedure to clean up or refine the result from the silhouette reconstruction procedure. Morphological operators are typical canonical operations used in post-processing procedures. Morphological operators involve non-linear operators operating on object shapes. Morphological transformation is given by the relation of

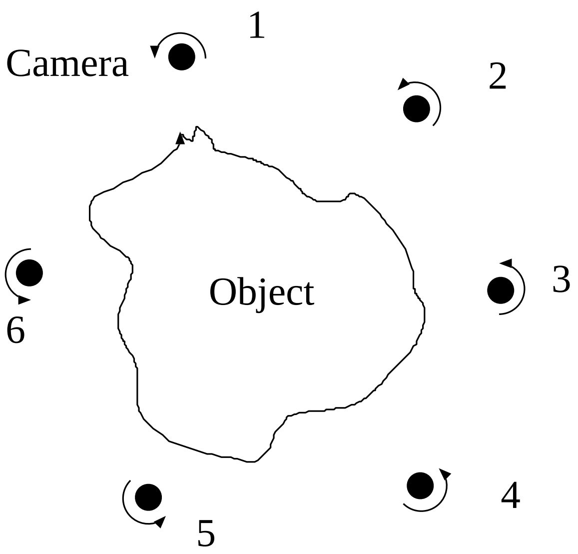

Figure 2: Shape reconstruction using multiple cameras

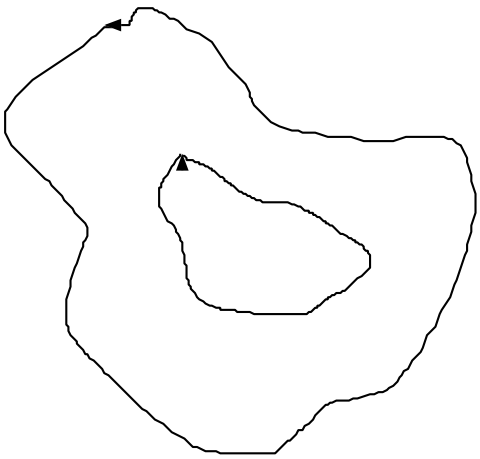

Figure 3: Convex Hall

the image X with another small point set B called structuring element. The two most important morphological operations are dilation and erosion.

2.1.1 Dilation

Translation of a binary image A by a pixel p shifts the origin of A to p. If $A_{b_1}, A_{b_1}, A_{b_1}, ..., A_{b_n}$ are the translations of the binary image A by the 1 pixels of the structuring element B then , the union of the translations of A by the value one pixels of B is called the dilation of A by B and is given by

$$A \oplus B = \cup A_{b_i} \tag{1}$$

2.1.2 Erosion

The erosion of a binary image A by a binary image B is 1 at a pixel p if and only if every 1 pixel in the translation of B to p is also 1 in A. Erosion is given by.

$$A \ominus B = \cap A_{b_i} \tag{2}$$

2.2 Voxel occupancy with graph cuts

Voxel occupancy approach involves reconstruction of a 3D shape of object using images from multiple views. This task can be formulated as energy minimization problem. The energy function just like the labeling problem has smoothness and data term.

$$E(f) = \sum_{veV} D_v(f_v) + \lambda \sum (1 - \delta(f_v - f_u)) \tag{3}$$

The smoothness term entails the number of empty voxels adjacent to filled ones. The data term is expressed as a sum over the individual voxels, where the penality for a voxel is based on the observed intensities of the pixels that intersect it. For a detailed explanation of the technique refer to the "Exact Voxel Occupancy with Graph Cuts" paper on the course web site.

2.3 Space Carving

The space carving is the state-of-the art shape reconstruction technique. It involves iterative "carving away" voxels from an initial volume that is known to contain the scene of interest. This method does not require correspondence information of points in the images but instead it relies on the testing the photo consistency of scene points to generate a reconstruction. Thus this technique generate reconstruction results which would reproduce input images when re-projected to the cameras used to acquire the images.

3 Optical flow

Motion can be seen as a generalization of a stero matching problem. In motion problem, the task is the reconstruction of the object scene which is in motion. The main issue that is different between stereo correspondence and motion problem is the occurrence of a two dimensional disparity field in motion.

In this lecture, Horn and Schunk's optical flow constraint equation technique(OFCE) for solving motion problem is discussed. The basic idea in OFCE is assuming images as "snapshots" of a continuous intensity function $I(x, y, t)$ where $x\ and\ y$ are distance coordinates and t represent time domain. The brightness is assumed to remain constant in this technique. A constant brightness behavior can be mathematically expressed as follows.

$$(\frac{dI}{dt}) = 0 \tag{4}$$

The optical flow equation is defined using the following terms.

- x component of velocity $u(x, y) = \frac{dx}{dt}$
- y component of velocity $v(x, y) = \frac{dy}{dt}$
- rate of intensity change in x direction $I_x = \frac{dI}{dx}$
- rate of intensity change in y direction $I_y = \frac{dI}{dy}$
- rate of intensity change with respect to time $I_t = \frac{dI}{dt}$

The optical flow constraint equation is given as follows.

$$\frac{dI(x, y, t)}{dt} = 0 = (\frac{dI}{dx})(\frac{dx}{dt}) + (\frac{dI}{dy})(\frac{dy}{dt}) + (\frac{dI}{dt}) \tag{5}$$

The above equation can be rewritten as follows using the terms defined above.

$$I_x u + I_y v + I_t = 0 \tag{6}$$

Using a gradient(∇) formulation, the above equation can be expressed as

$$[u\ v].\nabla I = -I_t \tag{7}$$