15 Building 3D Perception Using a Kalman Filter

15.1 Introduction

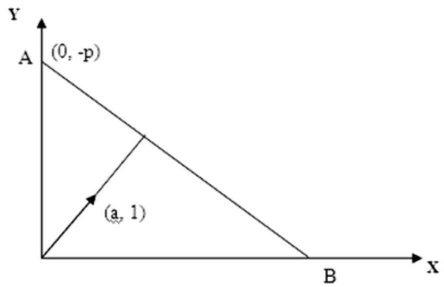
A Kalman filter is a recursive digital filter [Brown, 1997] that acts as a set of incoming data structures to estimate the parameters of a system. Ayache employed Kalman filtering [Ayache, 1987; Ayache, 1991] for 3D reconstruction of images. In fact the Kalman filter can be used to construct 2D lines from noisy 2D image points, affine 3D points from 2D image points, affine 3D lines from noisy 2D image points or from affine 2D lines or from 3D points, and 3D planes either from 3D points or 3D lines. Before employing Kalman filtering for 3D reconstruction, we will briefly outline the minimal parametric representation of 2D lines, 3D lines, and 3D planes. After the minimal representation, these parameters can be directly used to recursively update the filter equation in order to find the estimators of the system. A 3D reconstruction is required, generally, to find the depth information of an object. The images by which the depth can be measured are usually called stereo images. A number of cameras are employed to extract the features of the stereo images. The number of cameras is generally restricted to three for most image processing applications. The significance of the Kalman filter in 3D reconstruction lies in streamlining the process of feature extraction through multiple cameras. In this chapter, we present some experiments to construct (a) 3D points from noisy 2D image points, (b) a 3D line from 3D points and (c) a 3D plane from 3D points. Let us first discuss the possible minimal representation of 2D lines, 3D lines, and 3D planes.

15.2 Minimal Representation

A 2D line AB can be minimally best represented by two parameters **a** and **p** as evident from Fig. 15.1. The advantage of this parameterization is that the equation of the lines is linear in the parameters (a, p), which is essential

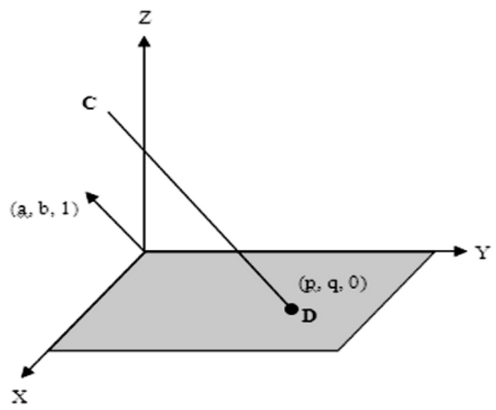
in the formulation of the recursive Kalman filtering equation. Secondly the state vector which is derived from these parameters satisfies the inequality check criteria of the recursive Kalman filter.

Similarly, the 3D line CD can be minimally represented by four parameters **a**, **b**, **p**, **q**, as shown in Fig. 15.2 and the plane EFGH can be represented by three parameters **a**, **b**, **p** as shown in Fig. 15.3.



$a\,x + y + p = 0$ (when the line is not parallel to the Y-axis), or
$x + a\,y + p = 0$ (when the lines are not parallel to the X-axis)

Fig. 15.1. A 2D line AB that passes through $(0,-p)$, normal to the line, passing through (0,0) and $(a,1)$, can be represented by two parameters **a** and **p**



$x = a\,z + p$ and $y = b\,z + q$ (when the line is not orthogonal to the Z-axis)
$y = a\,x + p$ and $z = b\,x + q$ (when the line is not orthogonal to the X-axis)
$z = a\,y + p$ and $x = b\,y + q$ (when the line is not orthogonal to the Y-axis)

Fig. 15.2. A 3D affine line CD that passes through the XY plane at a point $(p, q, 0)$ and having the direction vector $(a, b, 1)^T$ can be represented by four parameters **a**, **b**, **p**, **q**