Administrivia

Project information (rough draft) is now posted. This is under continuous construction for the next 7 days.

Note that you need to start thinking about this soon, and that you need to OK your plans with me. Often this will require seeing me. I am willing to create additional office hours **Wednesday afternoon** if this will help. Let me know!

Syllabus Notes

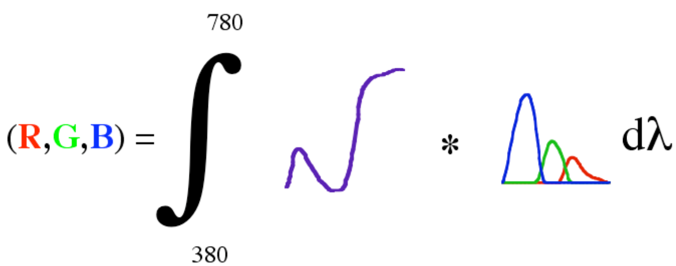
I am leaning towards the next assignment involving camera calibration, so we will do this more thoroughly sooner than originally advertised. (Parts of §2 and §3).

Aerial Robotics Club

For the record: The first 1/2 hour of the class was a presentation by the Aerial Robotics Club

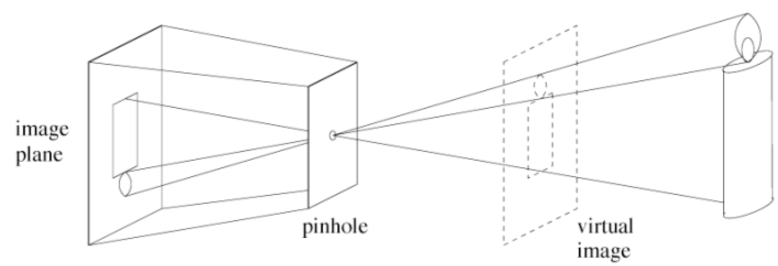
Cameras so far

- Model for the brightness due to light reaching a region (say, CCD element)



$$\square^{(k)} = F^{(k)}(\square^{(k)}) = \int L(\square)R^{(k)}(\square)d\square$$

- Model the image location corresponding to a point in the world by projection (developed using pinhole camera model).
- Represent using matrix multiplication using homogenous coordinates.



Cameras so far (continued)

- Real cameras need lenses
  - Brightness falls off towards edges
  - Focus now depends on distance (unlike pinhole cameras)
  - Aberations and distortions
  - Complex optical path leads to vignetting and flare (next slide)

Other (possibly annoying) phenomena

- Chromatic aberration
  - Light at different wavelengths follows different paths; hence, some wavelengths are defocussed
  - Machines: coat the lens
  - Humans: less resolution in short wavelenghts
- Scattering at the lens surface
  - Some light entering the lens system is reflected off each surface it encounters (sometimes referred to as Flare---a very difficult source of noise to purge or calibrate for)
  - Machines: reduce it by coating the lens, interior optical surfaces
  - Humans: live with it (various scattering phenomena are visible in the human eye)

Camera parameters (§2.2)

- Camera may not be at the origin, looking down the z-axis
  - extrinsic parameters (position and orientation of the camera)
- One unit in camera coordinates may not be the same as one unit in world coordinates
  - intrinsic parameters - focal length, principal point, aspect ratio, angle between axes.

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \begin{bmatrix} \text{Transformation} \\ \text{representing} \\ \text{intrinsic parameters} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \text{Transformation} \\ \text{representing} \\ \text{extrinsic parameters} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}$$

Note that the transformations have made it to that f=1 (see §2.2.1)

Camera calibration (§3)

- Issues:
  - what is the camera matrix? (intrinsic+extrinsic)
  - what are intrinsic parameters of the camera?
- General strategy:
  - view calibration object
  - identify image points
  - obtain camera matrix by minimizing error
  - obtain intrinsic parameters from camera matrix
- Error minimization:
  - Linear least squares
    - easy problem numerically
    - solution can be rather bad
  - More robust methods exist

$$
\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \underbrace{\begin{bmatrix} \text{Transformation} \\ \text{representing} \\ \text{intrinsic parameters} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \text{Transformation} \\ \text{representing} \\ \text{extrinsic parameters} \end{bmatrix}}_{\text{Camera matrix, } M} \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}
$$

Camera matrix, *M*

Goal one: find M from image of calibration object

Goal two: given M, find the two matrices

Is goal two feasible?

Is goal two feasible?

Reason by counting parameters. We have 12 numbers, as M is 3 by 4. The number of parameters are the number of intrinsic parameters *plus* the number of extrinsic parameters.

Extrinsic parameters: ?

Intrinsic parameters: ?

The number of parameters are the number of intrinsic parameters *plus* the number of extrinsic parameters.

Extrinsic parameters:	
location	(3)
orientation	(3)
Intrinsic parameters:	
focal length	(1)
pixel aspect ratio	(1)
principal point	(2)
skew	(1)
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Sometimes assume aspect ratio to be 1 and/or skew to be zero ==> 9

Is goal two feasible?

Yes (provided the points are not "degenerate"), up to a scale factor (camera distance and focal length cannot be distinguished).

(This can be resolved using more images or other knowledge)

Goal one: Find M from image of calibration object. The equation relating world coordinates is:

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = M \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix} = MP$$

If we identify enough non-degenerate points whose *world coordinates are known* then we can estimate M from their *location in the image*.

The above is the equation in terms of homogeneous coordinates. So we have to work in terms of the observed image coordinates, u=U/W and v=V/W