3. IMAGE ENHANCEMENT (1)

Enhancement in digital images

The image enhancement techniques are applied to images to:
- eliminate or significantly reduce image distortions caused by imperfect image generation process
- improve visual qualities of an image (contrast, sharpness, visibility of details, etc)

The main problems that image enhancement is trying to correct are geometric distortions and distortions in grey levels (tonal distortions).

Problem: geometric distortions

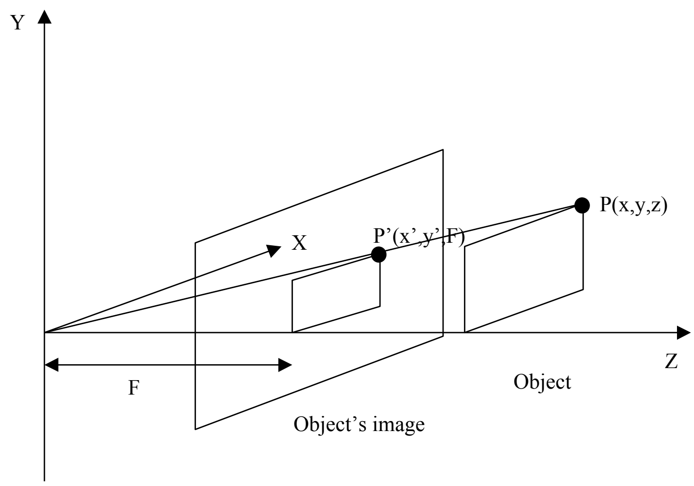
Causes

- sensor or camera geometry
- lens geometry (e.g. wide-angle)
- object geometry (e.g. curved surface)

Geometric model of the image

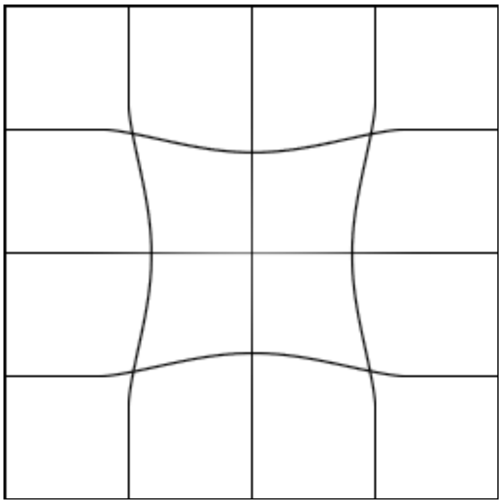
Image is projection of (normally) a 3D object onto a 2D surface. Understanding of geometry of this projection leads to formulation of methods for removing the undesirable effects of the projection. Point projection, which describes a geometric transformation of a point through an imaging device (an eye, a camera), provides a fundamental mathematical model.

The relation between the real point P and the is image (a projected point P') can be expressed by $P' = PF / (F - z)$, where F is a focal length. If F, and several other camera parameters are known, this equation provides the basis for computing 3D coordinates from a 2D image (see Gonzales & Woods, section 2.5, Imaging Geometry).



This model assumes that the imaging device itself does not distort the image. In reality it does; the geometrical model of a camera can be approximated from measurements on a test image. Consider, for example, two cases below where the camera lens introduced a distortion. By imaging a test grid using the same lens as used for imaging a scene, the distortion can be eliminated by using *warping* (see the exercises below).

Distorted image



Distorted grid, used to compute geometric correction

Geometric corrections involve

- the use of an appropriate model for corrections (camera model, projection model, a model image with known geometry)
- spatial interpolation of image values using the model

Problem: tonal distortions

Causes

- limited dynamic range of sensors
- exposure error

Contrast enhancement

There are a number of image processing techniques which can be used to remove tonal distortions, including:

- statistical methods, such as "histogram manipulation" for exposure correction
- digital filtering for image sharpening
- "de-illumination", a technique using the image frequency model (to be discussed later), for removing effects of uneven illumination

Histogram as a tool for correcting contrast distortions

Histogram is a frequency distribution graph; it shows the number of pixels in the image having a particular grey level or a range of grey levels.

Image properties captured by image histogram

- contrast
  - low - most pixels within a small portion of grey scale
  - high - bimodal histogram with peaks at outer brightness regions
- dynamic range
  - how widely occupied the grey scale is
  - small - all the pixels in a small portion of a grey scale
  - large - wide grey level scale distribution
- desired characteristics
  - medium or high contrast
  - large dynamic range

Histogram is one example of a *statistical model of the image*. It considers the image as a population of pixel values and it captures the statistics of this population. It is a very limited model as it completely ignores spatial distribution of pixels.

Histogram manipulations

Histogram manipulation techniques aim to change pixel values so that the histogram of the resulting image has desired characteristics, normally increased contrast and dynamic range. As the spatial location of pixels is not captured by histogram, image is changed by applying the same transformation T to each pixel in I(x,y). T is assumed to be monotonically increasing, single-valued and to have the inverse. A general expression for a histogram – changing linear transformation is the following *mapping function*:

$$I'(x,y) = C \cdot I(x,y) + B \qquad \text{for each pixel } (x,y)$$

Histogram manipulation is an example of *pixel point processing*, where the same transformation is applied to each pixel. It is a *context-free* operation.

Linear operations

- *shifting*
  lightning or darkening of the image
  by adding or subtracting a constant brightness to all pixels:
  $I'(x,y) = I(x,y) + B$
  effect: histogram shifted to the right or left

- *stretching*
  changing the contrast and dynamic range of the image
  by multiplying all the pixels by a constant value:
  $I'(x,y) = C \cdot I(x,y)$
  effect: histogram stretched or shrunk

Non-linear histogram operations

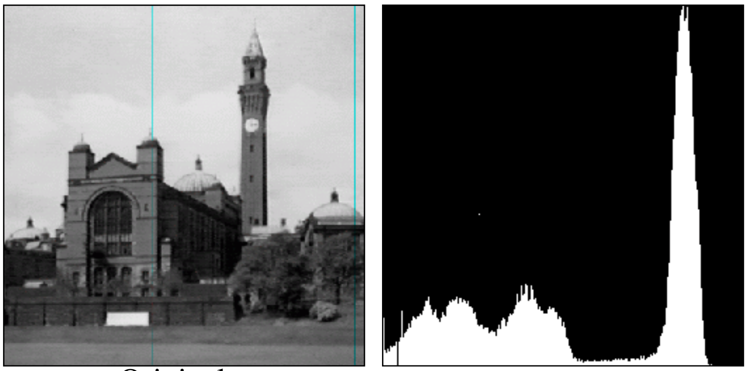
- *histogram specification*
  This technique changes image values so that the resulting image has the histogram as specified by the user. See HIPR for details of the technique.

  The most common application of histogram specification is *histogram equalisation*, which produces an output image with grey levels uniformly distributed

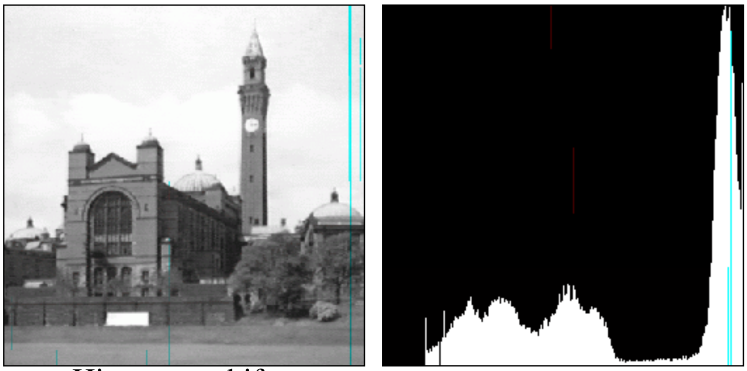
  Another common application is photometric correction which uses the gamma function as the the histogram model.

Examples are shown below.

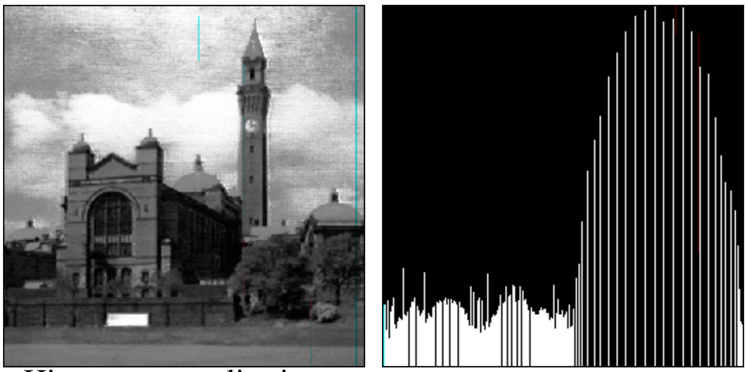
Image	Histogram	Plot a transfer function:



Original



Histogram shift



Histogram equalisation

Further reading and exploration

Bruce, V. et al Ch. 1.
Watt, R. Ch. 4 “Image Algebra”.
Sonka, M. et al, parts of Ch. 4. (4.1 and 4.2)
Gonzalez, R.C. & Woods, R.E. 2.5, 5.9, 4.1 and 4.2

HIPR

Worksheets->Geometric Operations:
Affine Transformation

Worksheets->Point Operations:
Thresholding
Contrast Stretching
Histogram Equalization
Logarithm Operator
Exponential / “Raise to Power” Operator

CVIP

Restoration -> Geometric Transforms
(read help files for explanation)
View histogram
Enhancement -> Histograms -> Slide
Enhancement -> Histograms -> Stretch and Shrink
Enhancement -> Histograms -> Equalisation
Enhancement -> Histograms -> Specification

EXERCISES

1. Display the image **cells1.tif**. (~exc/Teach/Images/Unit3) Note its dark appearance. Determine the range of grey level values in the image.
Determine statistical distribution of grey levels (image histogram).
Using image arithmetics modify the image values so that the image appearance is improved. Examine in the same way some other images.

2. The image **corr_ex.tif** shows a correctly digitised Kodak grey level scale where shades of grey vary from black to white, with luminance L changing by equal intervals (i.e. $L_i = L_{i-1} + k$). Examine the scale using the line profile. What kinds of distortions are introduced by the process of digitization? Compare this image with **under_ex.tif** which is an underexposed image of the same Kodak scale.

3. Display the image **grey_scale.tif** and examine its image profile.
Now, examine the image visually and try to assess the relationship between brightnesses of the consecutive patches. It is very likely that the *observed* differences in brightness between the patches are not uniform (why?). Change the colour mapping (e.g. via histogram specification) in such a way that the contrast between all the patches *appears* uniform. Observe the shape of the mapping function. Could this shape have been predicted theoretically - how?