3. RADIOMETRIC CORRECTION

Radiometric Correction: operations intended to remove systematic or random noise affecting the amplitude of an image function. The defects may be introduced during imaging, digitization or transmission of the image. The goal of correction procedures is to restore an image to the condition it would have been in if the imaging process were flawless.

Random noise: Random noise implies local variability, that is, pixel to pixel variation in gray value that is not related to changes in the signal from the target. The pixel-to-pixel variability suggests that random noise is, by nature, a high spatial frequency phenomenon. Thus, an operation that damps out high frequencies should also damp out random noise.

A mean filter will effectively damp out random noise. Unfortunately, it will also degrade the resolution of the image.

Impulse noise: Isolated pixels that are anomalously dark or bright. Impulse noise may arise as a result of a number of problems:
- a faulty detector in a 2-dimensional imaging array
- data dropouts during transmission, compression, decompression

With impulse noise the original cannot be recovered. Instead, the gray value must be replaced with something more reasonable. Typically, the gray value of the faulty pixel is replaced by an average gray value derived from a set of nearest neighbors.

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a) Example of impulse noise b) mean filter c) Mean filter with round off.

Figure 3.1 Impulse noise corrected using a mean filter applied to the entire image.

By defining a mask, or window, we may limit the area of concern to a small number of pixels near to the pixel in question. In the example above (Figure 3.1), the anomalous pixel (shaded) at the center of the window (bold border) has a much higher value than any of the neighboring pixels. One might "corrected" that single pixel by replacing its gray value with the mean of the 8 neighboring pixels, i.e., \(23 + 25 + 24 + 22 + 25 + 25 + 23 + 23 = 23.75\). Thus, the shaded pixel would be replaced with a gray value of 24 which is more representative of the local pixels.

The problem with this process is that the user must individually identify each anomalous pixel in the image. If the image is large and there are more than a few pixels in the image to deal with, this will be a very tedious process. Automating exist which are designed to alter only anomalous pixels based on user-selected criteria.
Some image processing systems that are designed for work with satellite and aircraft imagery (where impulse noise is a problem) will have routines that first check for anomalous pixels and replace the pixel only if it fits the criteria for being anomalous. Other image processing systems will only have filters that operate on every pixel in the image. Typical filters are the mean and median filters. The mean filter computes the mean value of all the pixels within a user-specified window (including the central pixel), and replaces the gray value of the pixel at the center of the window with the local mean. Since it is not specifically designed to deal with anomalous pixels, a mean filter will include the anomalous pixel in the average and will generally do a poor job of substitution. The process is illustrated in Figure 3.1.

A median filter will replace the gray value of a target pixel with the median gray value of the pixels within a window centered on the target pixel. The median is the gray value of the pixel for which half of the pixels in the window have greater (or equal) gray values and half the pixels have a smaller (or equal) gray value. The median filter will also include the anomalous pixel, but will not be skewed by it. In the example below (Figure 3.2), the anomalous pixel is replaced by the median gray value of 24 (Figure 3.2b). The filters can also be adapted to deal with special conditions. For example, the median filter can be constrained to replace the center value with the median value only if the center value is sufficiently different from the surrounding pixels:

If \( (g_o - \text{avg8}) > \text{stdev8} \)
then \( g_o = \text{median(avg8)} \)
else \( g_o \) is unchanged.

where: \( g_o \) = gray value of the center pixel
\( \text{avg8} \) = average of the 8 nearest neighbors.
\( \text{stdev8} \) = standard deviation of the eight nearest neighbors.

An example of an the effect of this adaptive median filter is shown in Figure 3.2c)

Figure 3.2 Treatment of impulse noise using a median filter.
Image suffering from impulse noise.
There are seven anomalous pixels, all in the upper left corner of the image (Hollister and Carpenter Halls). Five of them are fairly obvious, however, one of the anomalous pixels lies on the walkway to the West of Hollister Hall (bright background and near two edges) and a second lies in the parking area to the North of Carpenter Hall (bright background).

Image “corrected” using a median filter.
The median filter deals very effectively with all of the anomalous pixels without obvious damage to the image resolution, but it also alters details of the image. For example, the dark shadow on the North side of the “penthouse” on Hollister Hall is now barely perceptible. Also the dark rectangular structure on the light-colored roof on the East side of Carpenter Hall appears to have been rotated.

Image “corrected” using a despeckle routine.
The despeckle routine looks for pixels that differ significantly from their background, and alters those that are too different. This routine is more effective at maintaining image quality while removing six of the seven anomalous pixels. Only the pixel adjacent to Hollister Hall remains. Although not obvious in this image, there is some danger of real data being altered.

Image “corrected” using a mean filter.
The mean filter fails on all counts. This filter only dims the contrast of the anomalous pixels -- it does not remove them. At the same time, it perceptibly degrades the spatial resolution of the image (blurring).

Figure 3.3: Examples of the effect of various filters on impulse noise.
Systematic, non-periodic noise

Consider radiometric noise that is linear in gray value, i.e.:

\[ I(x,y) = M(x,y) F(x,y) + A(x,y) \]

where:  
- \( F(x,y) \) = noise-free image function  
- \( M(x,y) \) = position dependent multiplicative noise factor  
  - detector gain  
  - illumination variations  
  - transmission of optical system  
- \( A(x,y) \) = additive noise  
  - detector offset (dark current)  
  - surface reflection  
  - atmospheric absorption or scatter (path radiance)

\( I(x,y) \) = observed, digitized image function

Example 1: Transillumination

Correction procedure:
1. Determine \( A(x,y) \) (or set \( A(x,y) = 0 \) by turning off the room light.)
   - turn off the light table lamp, e.g., set \( M(x,y) = 0 \).
   - replace the film transparency with a uniformly black \((F(x,y)=0)\) piece of the same type of film. (The black film will minimize the amount of light interacting with the emulsion and reflecting from the lower surface of the film.)
   - collect an image, \( A(x,y) \)

2. Determine \( M(x,y) \)
   - use a clear piece of the same film (constant density is all that is really necessary), i.e., \( F_0(x,y) = F_0 = \text{constant} \).
   - collect an image: \( I_0(x,y) = M(x,y) F_0 + A(x,y) \)
   - Solve for \( M(x,y) \):
     \[ M(x,y) = \frac{I_0(x,y) - A(x,y)}{F_0} \]
3. Compute the corrected image function:

\[ F(x, y) = \frac{I(x, y) - A(x, y)}{M(x, y)} \]

Alternatively, since \( F_0 \) has no spatial dependence, the image may be corrected in a relative sense by simply subtracting off the constant term and dividing by \( F_0 \):

\[ \frac{I(x, y) - A(x, y)}{I_0(x, y) - A(x, y)} = \frac{F(x, y)}{F_0} \]

\( F(x,y)/F_0 \) is proportional to the true image function and lacks any spatial variability introduced by the lighting effects.

**Example 2**: Reflective illumination

- **Camera**
- **Non-uniform light source**
- **Photographic print, \( F(x,y) \)**

**M(x,y)** = illumination (irradiance) at the photo surface  
**F(x,y)** = image function (photo density)  
**A(x,y)** = surface reflection (reflection of \( M(x,y) \) at the film surface).

**Correction procedure**

1. Determine \( A(x,y) \)
   - replace the film transparency with a uniformly black (\( F(x,y)=0 \)) piece of the same type of film.  
   - collect an image, \( A(x,y) \)

2. Determine \( M(x,y) \)
   - use a clear piece of the same film (constant density is all that is really necessary), i.e., \( F_0(x,y) = F_0 = \) constant.  
   - collect an image: \( I_0(x,y) = M(x,y) F_0 + A(x,y) \)  
   \[ M(x, y) = \frac{I_0(x, y) - A(x, y)}{F_0} \]
   - Solve for \( M(x,y) \)

3. Compute the corrected image function:

\[ F(x, y) = \frac{I(x, y) - A(x, y)}{M(x, y)} \]

or correct the image in a relative sense as in Example 1.
Example 3: Atmospheric Correction

\[
A(x,y) = \text{path radiance (haze) due to atmospheric scattering.}
\]
\[
M(x,y) = \text{illumination of the surface by direct (solar) and diffuse (sky) sources multiplied by the transmission of the atmosphere.}
\]
\[
F(x,y) = \text{reflectance of the earth's surface.}
\]

1. **Dark object subtraction**
   
   If the atmosphere is uniform over the scene \[ A(x,y) = A_0 \] and a black (zero reflectance) object exists in the scene, then one may correct the image for path radiance by subtracting the gray value of the dark pixel from every pixel in the image:

   \[
   I(x,y) - A_o = M(x,y) F(x,y)
   \]

   Assumptions: - uniform atmosphere
   - a "dark object" exists

   Problems: - does not account for illumination variations
   - does not correct for atmospheric transmission effects
   - truly dark pixels are rare and dark pixels in all spectral bands are even rarer.

   Water (presumably clear, deep water) has often been chosen as the dark target. This is rarely exactly true.

2. **Ratioing**

   Suppose that the illumination and atmosphere are both spatially variable, but differ only by a constant factor, \( c \) from band to band, then

   \[
   M_2(x,y) = c M_1(x,y) \quad \text{and} \quad A_2(x,y) = c A_1(x,y)
   \]

   then dividing (pixel by pixel) the first band by the second yields a new image:

   \[
   \frac{I_1(x,y)}{I_2(x,y)} = \frac{M_1(x,y) F_1(x,y) + A_1(x,y)}{cM_1(x,y) F_2(x,y) + A_1(x,y)}
   \]

   If the path radiance is negligible: \( A_1(x,y) = A_2(x,y) = 0 \), then

   \[
   \frac{I_1(x,y)}{I_2(x,y)} = \frac{F_1(x,y)}{cF_2(x,y)}
   \]

   and the new image will be insensitive to variations in illumination and atmosphere.