Multiplicative noise

In signal processing, the term **multiplicative noise** refers to an unwanted random signal that gets multiplied into some relevant signal during capture, transmission, or other processing.

An important example is the speckle noise commonly observed in radar imagery. Examples of multiplicative noise affecting digital photographs are proper shadows due to undulations on the surface of the imaged objects, shadows cast by complex objects like foliage and Venetian blinds, dark spots caused by dust in the lens or image sensor, and variations in the gain of individual elements of the image sensor array.[1]

Speckle noise

Speckle is a granular 'noise' that inherently exists in and degrades the quality of the active radar, synthetic aperture radar (SAR), medical ultrasound and optical coherence tomography images.

The vast majority of surfaces, synthetic or natural, are extremely rough on the scale of the wavelength. Images obtained from these surfaces by coherent imaging systems such as laser, SAR, and ultrasound suffer from a common phenomena called speckle. Speckle, in both cases, is primarily due to the interference of the returning wave at the transducer aperture. The origin of this noise is seen if we model our reflectivity function as an array of scatterers. Because of the finite resolution, at any time we are receiving from a distribution of scatterers within the resolution cell. These scattered signals add coherently; that is, they add constructively and destructively depending on the relative phases of each scattered waveform. Speckle noise results from these patterns of constructive and destructive interference shown as bright and dark dots in the image [1]

Speckle noise in conventional radar results from random fluctuations in the return signal from an object that is no bigger than a single image-processing element. It increases the mean grey level of a local area.[2]

Speckle noise in SAR is generally serious, causing difficulties for image interpretation.[2][3] It is caused by coherent processing of backscattered signals from multiple distributed targets. In SAR oceanography, for example, speckle noise is caused by signals from elementary scatterers, the gravity-capillary ripples, and manifests as a pedestal image, beneath the image of the sea waves.[4][5]

The speckle can also represent some useful information, particularly when it is linked to the laser speckle and to the dynamic speckle phenomenon, where the changes of the speckle pattern, in time, can be a measurement of the surface's activity.

Speckle Noise Reduction

Several different methods are used to eliminate speckle noise, based upon different mathematical models of the phenomenon.[4] One method, for example, employs *multiple-look processing* (a.k.a. *multi-look processing*), averaging out the speckle noise by taking several "looks" at a target in a single radar sweep.[2][3] The average is the *incoherent average* of the looks.[3]

A second method involves using adaptive and non-adaptive filters on the signal processing (where adaptive filters adapt their weightings across the image to the speckle level, and non-adaptive filters apply the same weightings uniformly across the entire image). Such filtering also eliminates actual image information as well, in particular high-frequency information, and the applicability of filtering and the choice of filter type involves tradeoffs. Adaptive speckle filtering is better at preserving edges and detail in high-texture areas (such as forests or urban areas). Non-adaptive filtering is simpler to implement, and requires less computational power, however.[2][3]

There are two forms of non-adaptive speckle filtering: one based on the mean and one based upon the median (within a given rectangular area of pixels in the image). The latter is better at preserving edges whilst eliminating noise spikes, than the former is. There are many forms of adaptive speckle filtering, including the Lee filter, the Frost filter, and the Refined Gamma Maximum-A-Posteriori (RGMAP) filter. They all rely upon three fundamental assumptions in their mathematical models, however:[2]

- Speckle noise in SAR is a *multiplicative* noise, i.e. it is in direct proportion to the local grey level in any area.[2]
- The signal and the noise are statistically independent of each other.[2]
- The sample mean and variance of a single pixel are equal to the mean and variance of the local area that is centred on that pixel.[2]

The Lee filter converts the multiplicative model into an additive one, thereby reducing the problem of dealing with speckle noise to a known tractable case.[6]

Wavelet Analysis

Recently, the use of wavelet transform has led to significant advances in image analysis. The main reason for the use of multiscale processing is the fact that many natural signals, when decomposed into wavelet bases are significantly simplified and can be modeled by known distributions. Besides, wavelet decomposition is able to separate noise and signal at different scales and orientations. Therefore, the original signal at any scale and direction can be recovered and useful details are not lost.[7]

The first multiscale speckle reduction methods were based on the thresholding of detail subband coefficients.[8] Wavelet thresholding methods have some drawbacks: (i) the choice of threshold is made in an ad hoc manner, supposing that signal and noise components obey their known distributions, irrespective of their scale and orientations; and (ii) the thresholding procedure generally results in some artifacts in the denoised image. To address these disadvantages, non-linear estimators, based on Bayes' theory were developed.[7]