SPECKLE REDUCTION WITH EDGE-PRESERVING

Pierre Mathieu, Laurent Dirat, Xavier Dupuis, Michel Barlaud member IEEE

Laboratoire I3S URA 1376 CNRS
Université de Nice-Sophia Antipolis
Bat. 4 SPI Sophia Antipolis
250, av. A. Einstein
06560 Valbonne - FRANCE
mathieu@unice.fr

ABSTRACT

Coherent imagery emerges as one of the major domains in image processing and includes topics as diversified as radar, medical and surface analysis. Whatever the application, the resulting image is noisy corrupted. In coherent imaging, images suffer from speckle noise [1], whose main characteristic is to be multiplicative. The proposed method takes explicitly into account the multiplicative property of the noise while preserving discontinuities in the restored image. Moreover, in a second step our algorithm estimates the noise, thus the information contained in the speckle still remains usable.

1. INTRODUCTION

Well known methods for reducing speckle are homomorphic filtering [3] where the multiplicative nature of the noise suggests a logarithmic transformation in order to get an additive noise. By the way, we can use classical methods such as Wiener filtering and Tikhonov regularization. This method presents two main drawbacks. First, numerical difficulties arise for values near zero. Second, the probability density function (pdf) of the transformed signal is no more gaussian, even though most of the classical filtering technics are optimal for gaussian distributions.

Another approach consists in multiscale processing (for example wavelets transform [2]) to reduce noise concentrated in some subimages. The multiplicative aspect of the noise is neglected in all these methods. In this paper we proposed a new algorithm which take into account this aspect, in order to improve the image estimation. In actual fact, we alternatively estimate both image and noise. The enhancement is shown from the numerical and experimental results.

2. MODEL

Let us state the following multiplicative model:

\[ Y = X_d . B = B_d . X \] (1)

with :

\[ X_d = \text{diag}(X) \quad \text{and} \quad B_d = \text{diag}(B) \]

Y represents the magnitude of the observed image, X the image and B a multiplicative noise.

In image processing, the knowledge of the measured data and the model is not sufficient to determine a satisfying solution (ill-posed problem). It is necessary to impose constraints on the solution. Then we assume as a priori that the noise intensity follows a Gamma pdf, and is independant and identically distributed over all the image.

Since variable are modulus images, we can assume that :

\[ \forall i \in [1..n] \quad \begin{cases} y_i > 0 \\ x_i > 0 \\ b_i > 0 \end{cases} \] (2)

The problem now is to estimate both image and noise.

3. ESTIMATION OF BOTH IMAGE AND NOISE

To introduce an a priori on image X, a Markov Random Field (MRF) is assumed with the Gibbs density function. The potential function (\( \phi \)) applied on the gradient of the image (\( \nabla X \)) is chosen in order to preserved edges. The Maximum A Posteriori (MAP) estimate is given by the criterion :

\[ J(X, B) = J_1(X, B) + \lambda_2 J_2(X) \] (3)
where

- \( J_1(X, B) = \| Y - B_d X \|^2 = \| Y - X_d B \|^2 \)
  represents the data term

- \( J_2(X) = \sum_{ij} \left[ \varphi \left( \frac{x_{i,j} - x_{i,j}}{\delta} \right) + \varphi \left( x_{i,j+1} - x_{i,j} \right) \right] \)
  represents the regularization term where \( \varphi \) is the potential function and \( \delta \) a threshold level from which we decide to preserve or to smooth the edges [4]. The \( \varphi \) function must satisfy some properties which can in particular be found in [5].

Moreover, the noise intensity is distributed according to a Gamma pdf. And, the \( i \)-th component \( b_i \) of \( B \) has as probability density function (for a normalized \( L \)-look multiplicative fading process [7])

\[
p(b_i) = K \frac{b_i^{2L-1}}{\sigma^{2L}} \exp \left[ -\frac{b_i^2}{2\sigma^2} \right] \tag{4}
\]

with

\[
K = \frac{1}{2^{L-1} \Gamma(L)}
\tag{5}
\]

where we infer the law of \( B \):

\[
p(B) = \prod_i \frac{b_i^{2L-1}}{\sigma^{2L}} \exp \left[ -\frac{b_i^2}{2\sigma^2} \right] \tag{6}
\]

Maximizing this probability leads to minimizing the log-likelihood:

\[
J_3(B) = -\ln [p(B)] = -\sum_i \ln \left( K \frac{b_i^{2L-1}}{\sigma^{2L}} \exp \left[ -\frac{b_i^2}{2\sigma^2} \right] \right)
\tag{7}
\]

Thus, we propose to minimize the following criterion:

\[
J(X, B) = J_1(X, B) + \lambda_2 J_2(X) + \lambda_3 J_3(B) \tag{8}
\]

4. ALGORITHM

The following alternate minimization of \( J \) is proposed to compute a solution:

- When \( B \) is fixed, the new estimate of \( X \) is given by solving \( \frac{\partial J(X, B)}{\partial X} = 0 \) which yield to the linear equation [4]:

\[
\left( B_d^T B_d + \frac{\lambda_2^2}{\delta^2} \Delta_{pond} \right) X = B_d^T Y \tag{9}
\]

with \( \Delta_{pond} \), a discrete approximation of a weighted laplacian. At site \((i,j)\), the coefficients are given by:

\[
\begin{pmatrix}
0 & \lambda^N & 0 \\
\lambda^W & 0 & \lambda^E \\
0 & \lambda^S & 0
\end{pmatrix}
\tag{10}
\]

The weights are defined as follow:

\[
\begin{align*}
\lambda^W &= \frac{\varphi'(x_{i,j} - x_{i,j})}{2|x_{i,j} - x_{i,j}|} \\
\lambda^E &= \frac{\varphi'(x_{i,j+1} - x_{i,j})}{2|x_{i,j+1} - x_{i,j}|} \\
\lambda^N &= \frac{\varphi'(x_{i,j} - x_{i,j})}{2|x_{i,j} - x_{i,j}|} \\
\lambda^S &= \frac{\varphi'(x_{i,j} - x_{i,j})}{2|x_{i,j} - x_{i,j}|}
\end{align*}
\tag{10}
\]

- When \( X \) is fixed, we compute the new image’s estimate derivating the criterion \( J(X, B) \) with respect to \( B \). Thus we obtain the normal equation:

\[
\left( X_d^T X_d + \frac{\lambda_2^2}{2\sigma^2} I \right) B = X_d^T Y + \left( 2\sigma^2 I \right) \frac{\lambda_2^2}{2} B^{-1} \tag{11}
\]

with 

\[
B^{-1} = \left( \frac{1}{b_1}, \ldots, \frac{1}{b_i}, \ldots, \frac{1}{b_n} \right) \tag{11}
\]

Note that each \( b_i \) is solution of a second order equation, given by the positive value (2).

We propose the following algorithm:

\[
\begin{align*}
B^0 &= \text{Noise's initial guess} \\
X^0 &= \text{Image's initial guess}
\end{align*}
\]

Repeat

- Compute new estimate \( X^{n+1} \) solving (9)
- Compute new estimate \( B^{n+1} \) solving (11)

Until convergence

5. EXPERIMENTAL RESULTS

The experimentation of this algorithm was processed both on a 64x64 pixels synthetic data, and on a real SAR image (3-look).

First, on a 64x64 pixels synthetic phantom derived from Shepp & Logan’s phantom (1-look). The potential function used is the Green’s function [9] \( \varphi_{GR}(u) = \log[cosh(u)] \) and the regularizing parameters are \( \lambda_2 = 2.3 \), \( \delta = 1 \) and \( \lambda_3 = 0.75 \).

The results (figures 1, 2, 3) presented are the original image, the noisy image, the regularized image, the noise’s estimate image and a cross section of the three firsts image at the 27-th line.
Secondly, on a real ERS-1 (©ESA) SAR\textsuperscript{1} image (3-look) of Saragosse (Spain). The potential function used is the Green's function [9] and the regularizing parameters are $\lambda_2 = 50$, $\delta = 1$ and $\lambda_3 = 25$.

The results (figures 4, 5, 6, 7, 8, 9) presented are the original 3-look modulus image, the restored image, the edges image and the histogram plots.

6. CONCLUSION

We observe a good restoration of the image with a significant noise reduction. The noise estimation is accurate on the flat areas, while on the edges, it strongly depends on the model of the discontinuities.

Future works concern the improvement of our edges model, by taking strongly into account the a priori on the noise, for example mean and variance.

7. REFERENCES


Figure 1: (a) Original image. (b) Noisy Image.

Figure 2: (a) Restored image. (b) Noise estimate.

Figure 3: (a): Original; (b): Noisy; (c): Restored.

\textsuperscript{1}Courtesy image by ESA for IGN, PNTS, GDR ISIS of CNRS.
Figure 4: Original image.

Figure 5: Restored image.

Figure 6: Edges image.

Figure 7: Original image histogram.

Figure 8: Restored image histogram.

Figure 9: Estimated noise histogram.