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Bitslice Noise Reduction using Mathematical Morphology

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ABSTRACT
This paper presents a noise reduction proposal based on
the application of binary morphological operation to
bitslices of images. The technique is applied to real and
simulated synthetic aperture radar images, and it is eva-
uated with a methodology based on statistical measu-
res. This nonlinear one step procedure is shown to
reduce the high grey level noise.

1. INTRODUCTION
It is well known that synthetic aperture radar (SAR)
images are corrupted by a signal dependent noise called
speckle. Many filtering techniques have been proposed
in literature (see, for instance, [Ref. 4]), and most of
these filters are based on some statistical properties of
the data. A complete account of the statistical proper-
ties of amplitude SAR data can be seen in [Ref. 2].

Mathematical Morphology is a non linear approach to
signal processing, which proved its usefulness in image
information extraction and in noisy data filtering. It is
based on mappings between complete lattices in terms
of some families of simple (elementary) transforma-
tions: dilations, erosions, anti—dilations, anti—ero-
sions. These mappings are built by combining these ele-
mentary transformations through the union, intersec-
tion and composition operations [Ref. 1].

Mathematical Morphology was initiated by G.
Matheron and J. Serra at the École des Mines de Paris.
It is called "Morphology" since it aims at analysing the
shape of objects. It is "Mathematical" in the sense that
this analysis is based on set theory, topology, lattices,
etc. This theory ranges from binary (where the linear
image processing approach was not efficient) to grey
scale image analysis.

In this paper, binary morphological operations are
applied to bitslices of images, aiming at reducing
speckle noise. Instead of making a statistical approach
to the observed grey levels, it is assumed that the noise
creates small black (white resp.) spots over white
(black resp.) fields, and binary operations are applied
in order to reduce the extent and intensity of these spots
before reconstructing the image.

There is a connection between this method and the sta-
tistical modelling of the data. It arises assuming that
every bitslice is the outcome of a binary Markov ran-
don field (possibly an Ising model with a convenient
neighbourhood structure) corrupted by binary noise.
The "filter" is constructed looking for uncorrupted
versions (estimators) of every bitslice. Though this
approach will not be followed in this paper, it is interest-
ing to bear in mind this connection.

2. DEFINITIONS AND NOTATION
Consider a finite rectangular lattice of the form
\( E = \{0, \ldots, m - 1\} \times \{0, \ldots, n - 1\} \). In every
\( s \in E \) a grey level \( y(s) \in K = \{0, \ldots, k - 1\} \) is
observed. Therefore, an image \( y = (y(s))_{s \in E} \) can be
seen as a function \( y : E \rightarrow K \) or an element of \( K^E \).
Consider \( f, g, f \) generic elements of \( K^E \).

Assuming that every observed value is a byte, it can be
represented as \( y(s) = [b_7(s), \ldots, b_0(s)] \), the bits (from
most to least significant) forming the byte observed in
\( s \). If \( f \) is a digital image format \((k = 2^8 \) for instance)\),
also lead to this representation.

The bitslice decomposition of the byte image \( y \) consists
of the eight binary images \( b^\iota : E \rightarrow \{0, 1\} \), with
\( 7 \geq \iota \geq 0 \), given by the observed bits in every coor-
dinate, denoted by \( y = [b^7, \ldots, b^0] \), where
\( b^\iota = (b^\iota(s))_{s \in E} \).

Efficient algorithms for this bit image extraction are
available in most programming languages, and an
arithmetic approach can be seen in [3]. Conversely, it is clear that restoring a grey level image from its bitslices is an easy task. This one–bit plane representation can be also used for image compression.

Figure 1 presents a grey scale image and its eight slices, ordered from most ($b^1$) to least ($b^8$) significant (bearing most its least information, respectively). The reader may notice that there is evident information up to the fourth bitslice, and with some effort some structure can be seen in the fifth.

The methodology here proposed for noise reduction consists of restoring the bitslices using mathematical morphology binary transformations, and then reconstructing the “filtered” image by stacking the bitplanes.

Denote the set of integers as $Z$, and let $B$ be a subset of $Z^2$ called structural element. The translation of $B$ by any vector $h \in Z^2$ is denoted by $B_h$ and given by $B_h = \{s + h : s \in B\}$. The transpose of $B$ is denoted by $B'$ and defined by $B' = \{-s : s \in Z^2 : s \in B\}$.

The dilation of $f$ by $B$ is the function $\delta_B(f) \in K^E$, given by, for any $s \in E$ by

$$\delta_B(f)(s) = \max \{f(s') : s' \in B', s \in E\}.$$.

The erosion of $f$ by $B$ is the function $\varepsilon_B(f) \in K^E$, given by, for any $s \in E$ by

$$\varepsilon_B(f)(s) = \min \{f(s') : s' \in B, s \in E\}.$$.

In these definitions the conventions $\max(\emptyset) = 0$ and $\min(\emptyset) = k$ were used.

The transformations $\gamma_s$ and $\phi_s$ from $K^E$ to $K^E$, given by the following compositions

$$\gamma_s = \delta_B f_s,$$

and

$$\phi_s = \varepsilon_B f_s,$$

are called respectively, morphological opening and closing with respect to $B$. More details about these transformations can be seen in [Ref. 1].

An opening (closing, resp.) transformation removes small spurious regions of white (black, resp.) pixels in regions smaller than the size of $B$. These transformations are called morphological filters [Ref. 5], and this class of filters is very important because its members exhibit one-step convergence (they are idempotent operators).

3. METHODOLOGY

Let $f = \{b^1, b^2, b^3, b^4, b^5, b^6, b^7, b^8\}$ be the original image and its bitslice decomposition. Assume that it is desirable to reduce the noise present in $f$, and that morphological binary operations will be used to filter $\{b^1, ..., b^8\}$. Amongst the many ways to tackle this task, two specifications have to be made:

1. Which bitslices will be filtered?
2. Which operations will be applied in order to filter the chosen bitslices?

The theoretical answer for both questions is beyond the scope of this work, and unknown to the authors.

The spurious noise in a slice is represented by small areas with black and white spots. Closing and opening transformations reduce small spurious regions of white and black pixels, so they are well adapted to solve this kind of problem. Remains open the question of the structuring element to be used.

Regarding which bitslices will be subjected to the filtering, it is intuitive that the more biplanes filtered the smoother should be the final image, and that the computational effort is proportional to the number of filtered slices. Also, since most of the information lies in the most significant bitslices those are the natural candidates to be filtered. Figure 2 shows the general methodology representation.

An empirical approach is here proposed, based on the use of a simulated image. A true image (phantom) exhibiting two homogeneous areas, one dark one bright, is corrupted by one look amplitude speckle noise in a multiplicative manner [Ref. 2, 6]. The original and corrupted images are shown in Figure 3. The phantom here considered allows the simultaneous evaluation of noise reduction (over homogeneous areas) and the preservation of fine details (points and lines).
It was decided to evaluate the bitslice image reconstruction provided by a opening closing filtering operation given by:

\[ F = \gamma \delta \phi \cdot B = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \]

where "." indicates where is the origin of structural element.

The "most filtered" image is that obtained by reconstructing (stacking) the eight filtered bitslices (i.e., \(\{F(b^1), ..., F(b^8)\}\), denoted here as \(F_0\)). The "second most filtered" image is that obtained by reconstructing the seven most significant filtered bitslices with the least significative left unaltered (i.e., \(\{F(b^1), ..., F(b^7)\}\), denoted here as \(F_1\)). Proceeding in this way, the sequence of filtered images \(F_0, F_1, F_2, \ldots, F_8\) and \(f_1 = \{F(b^1), b^2, ..., b^8\}\) can be constructed, where the subscript denotes the number of filtered bitslices used in the reconstruction and where \(f_1\) denotes the "least filtered" image. Figure 4 shows each bitslice of phantom and Figure 5 shows these bitslice filtered. Figure 6 shows one look amplitude corrupted phantom and result of three most significative bit plane bitslice filtered images.

As a measure of noise reduction the equivalent number of looks of the filtered images over both areas was calculated. Table 1 shows the equivalent number of looks (ENL) estimated over several filtered versions of corrupted phantom which, by construction, has one look noise. From this table the following conclusions can be drawn:

a) the quality of reconstruction increases, when measured by the equivalent numbers of looks, with the depth of the filtering.

b) this growth is non-linear, and seems to be negligible after \(b^7\) has been processed.

c) the noise reduction is different for the dark and bright areas, being stronger for the latter.

A side effect of this technique is an increase in the mean of the areas, due to the fact that the transformation \(F\) starts with a closing transformation.

<table>
<thead>
<tr>
<th>ENL</th>
<th>Dark</th>
<th>Bright</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_1)</td>
<td>0.99</td>
<td>4.42</td>
</tr>
<tr>
<td>(f_2)</td>
<td>2.97</td>
<td>9.91</td>
</tr>
<tr>
<td>(f_3)</td>
<td>5.31</td>
<td>14.56</td>
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<tr>
<td>(f_4)</td>
<td>6.68</td>
<td>16.60</td>
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<tr>
<td>(f_5)</td>
<td>7.34</td>
<td>17.50</td>
</tr>
<tr>
<td>(f_6)</td>
<td>7.89</td>
<td>18.01</td>
</tr>
<tr>
<td>(f_7)</td>
<td>7.89</td>
<td>18.07</td>
</tr>
</tbody>
</table>
4. RESULTS

The technique that consists of filtering the bitslices version of $f = \{b^7, \ldots, b^0\}$ was applied to two SAR images, one obtained by the SAR580 sensor over Freiburg, Germany (image $g$), and the other obtained by the JERS–I sensor over Tapajós, Brazil (image $h$).

Figure 7 shows the original $g$ image of Tapajós with approximately four looks and its bitslices. $g$ is one byte amplitude. Figure 8 shows the most significative bitslices of $g$ after filtering. Figure 9 shows the original image and the filtered version $g = \{F(b^7), F(b^6), F(b^5), b^4, b^3, b^2, b^1, b^0\}$ images.

Fig. 4 — Bitslices $\{b^7, \ldots, b^0\}$ from one look corrupted phantom.

Fig. 5 — Filtered bitslices $\{F(b^7), \ldots, F(b^0)\}$ from one look amplitude corrupted phantom.

Fig. 6 — One look amplitude corrupted phantom and result of its filtering three most significative bitslices.

Fig. 7 — JERS–I image over tapajós, and its filtered version.
Synthetic aperture radar (SAR) images are corrupted by speckle and many filtering techniques have been proposed in the literature. This paper presented a noise reduction based on binary morphologic application to bitslices of images.

Table 1 showed that the equivalent number of looks of morphological filtered image increases with the depth of the filtering and this increase is non-linear.

This methodology increases the mean and generates more homogeneous images (see Figure 6, Figure 9 and Figure 11).

The mean increases is due to the fact that the transformation $F$ (morphological filter) starts with a closing transformation.

Some questions like which bitslice will be filtered and which operations will be applied are beyond the scope of this work and are not quite solved by the authors.

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7. REFERENCES


