Analysis by Wavelet Frames of Spatial Statistics in PALSAR Data for Characterizing Structural Properties of Forests

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In this talk we will describe a number of experiments whose goal is to assess whether spatial statistics (texture) in PALSAR data bears information on the horizontal structure of forests, which in turn could potentially be used to retrieve bio-physical attributes regarding species and development stages. The study is conducted from a purely observational standpoint, and no attempt will be made to justify rigorously or give physical explanations of the observed phenomena. The underpinning analytical gear is based on the generation of texture measures by wavelet frames. Therefore this talk will be the story of three characters - forests, PALSAR observations and wavelets - that are pulled together by some force of destiny (called sometimes research) in an attempt to pursue a good end.

degragl, 31/10/2008
Objective:
To assess whether spatial statistics (texture) in PALSAR data give information on the horizontal structure of forests which can be used potentially to retrieve biophysical attributes relating to species and development stages.

G. De Grandi, J.S. Lee, D.L. Schuler,

"Target Detection and Texture Segmentation in Polarimetric SAR Images Using a Wavelet Frame: Theoretical Aspects",


Augustine as depicted by Sandro Botticelli, c. 1480
In previous presentations (which some of you could have had the bad luck to attend) we have pondered on philosophical issues, such as how this profound idea of texture descended on humankind, and consequently we set forth to develop some theoretical background on how to measure texture by wavelets (refer to this paper for details).

degrai, 31/10/2008
If nobody asks me what the time is, I believe I know but if somebody asks me, I do not know.

Texture is difficult to define; there is no solid mathematical definition.

G. De Grandi, J.S. Lee, D.L. Schuler,
"Target Detection and Texture Segmentation in Polarimetric SAR Images Using a Wavelet Frame: Theoretical Aspects",
Can we experimentally measure polarimetric texture in PALSAR data?

Eppur si muove (Yes it moves).... if I change polarization!

Galileo Galilei

(Experimental father in physics)

Portrait of Galileo Galilei by Justus Sustermans (1597-1681), ca. 1639

If the polarisation changes, do the texture and spatial statistics change as well?
We are now steering, thanks to Galileo's help, towards the experimental method, and will discuss in the following more the nuts and bolts side of the business. Before talking about results let us first have a look at the hammers and wrenches, the tools that we use for our measurements.

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TEXTURE MEASURES OF POLARIMETRIC SAR DATA BY WAVELET FRAMES

WAVELET ENERGY IN A HYPERSPACE
(Texture measures depend on several variables)

SPACE (x, y)
SCALE (resolution)
POLARIZATION STATE (HH, VV, HV or any combination)

Need to reduce variables (e.g., for graphical representation)

- Zero - A point in the image (a pixel)
- Y - Dimensionless value (multiply by the value in the image)
- X - Distance of pixels from the point (which relates to scale)
- Image is multiplied by the function to give positive and negative values
- Image is then squared (to give wavelet variance)
- Values of resulting image are greater where more texture and lower where less texture
- Function can be dilated or contracted to give gradient (derivative) at different scales (e.g., 1-16)
The process of generating texture measures from SAR data by wavelet frames can be interpreted as a mapping by some wavelet mysterious machinery from a space where SAR polarimetric data are described (for instance the scattering matrix representation) onto an hyperspace holding the wavelet energy, whose domain has several dimensions: two spatial coordinates (e.g. range and azimuth), scale and polarization states. Incidentally, the mysterious wavelet machine is just producing wavelet energy at a number of dyadic scales.

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TOOLS FOR TEXTURE MEASURES REPRESENTATION IN A REDUCED SPACE
WAVELET SCALING SIGNATURE (WASS)

In effect, wipes out:
• Polarisation (as taking a single channel)
• Position (as taking an area)

To reduce dimensions:
• Take one polarization (e.g., HH; and for closed forest)
• Apply in two directions (range, azimuth) and average wavelet variance within a polygon (gives one variable)
• Apply at variable scales to highlight the scale at which texture develops.

In effect, wipes out:
• Polarisation (as taking a single channel)
• Position (as taking an area)
Hence the need arises to reduce this hyperspace and arrive at a condensed representation of the various dependences of texture measures, and in a way that could be mapped into a two-dimensional graph. These reduced graphical representations are what we call texture signatures. The first member of the family is the wavelet scaling signature, in short WASS. It works like this. A region of interest is defined on the SAR data by means of a vector file. The wavelet machinery is applied to detected power data at a certain polarization state. The average wavelet energy over the area of interest in computed along the two orthogonal directions afforded by the frame decomposition. Therefore the signature consists of a graph of local estimates of the wavelet variance computed at one polarization as a function of scale, as we can see in the next slide.
WAVELET SCALING SIGNATURE (WASS)

WASS deals with a single polarisation

- $\log_2 W$ is the average in the x and y dimensions from a point (average of the polygon)

- Lower values of $\log_2 W$ indicate less texture whilst higher values indicate more texture

- The $\log_2$(scale) indicates the distance (scale)
  - $\downarrow$ 2, 4, 8, 16 pixels

- Can establish whether stationary or non-stationary
As the word suggests, the WASS highlights for detected data at one specific polarization state, the dependence of texture strength on scale. The signature is particularly useful when dealing with the statistical characterization of scale-invariant random process that eventually underpin our textured image. For scale invariant noise processes it is possible to establish a relationship between the power spectrum scaling exponent and the wavelet variance scaling exponent. Now, the power spectrum scaling exponent can gives us clue about a stationary (gamma < 1) or non-stationary process (gamma >1). Therefore a WASS graph with linear negative slope (decreasing variance with increasing scale) will indicate a stationary process (such as speckle) and a graph with positive slope, a non-stationary process, such a mono-affine fractal processes. The blue line is for white noise, and marks the margin between the two regimes.

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TOOLS FOR TEXTURE MEASURES REPRESENTATION IN A REDUCED SPACE
WAVELET POLARIMETRIC SIGNATURE (WASP)

- WASP deals with $n$ polarisations
- Polarimetric data are not transformed into power image
- Instead, power is synthesized and the wavelet variance for each polarisation state (1 to $n$) determined
- Obtain an average wavelet variance for the polygon for each scale and polarisation state.
- Indicates, in this example (buildings), that there is more texture at a scale of 8 and this is associated with a tilting of the cross polarised axis at 45°
- Texture (measured as $W^2$) decreases at 16 but also at 2 and 4
The second member of the family is the Wavelet Polarization Signature, or WASP. This signature is the one that will eventually capture dependences of texture measures on polarization state. In this case we start with the covariance matrix representation of our pol data, and apply the wavelet machinery to all elements of the matrix. In other words, we decompose the matrix into the wavelet frame space. Then we choose a set of polarization states (usually a subset of a linear cross-polarized configuration at a number of orientation angles), apply the power synthesis operator, and make an average of the resulting wavelet coefficients energy over the whole area of interest. We will therefore obtain a family of graphs, each showing the wavelet variance versus pol state, and parametrized by scale.

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• WASPSEF is a separability measure to see how one area is spectrally different from another.

• In this example, separability is greatest at a scale of 8 and at HV polarisation.
Last but not least, we look into textural separability between two regions. Up to now we have measured texture within an area. Still, these are local measures and tell us nothing about the possibility of distinguishing two regions, a fact which is important if we want to make the passage to classification. This signature, called the Wavelet Fischer Separability Signature, in short WASEF, achieves the goal by applying the Fischer linear discriminant analysis separability criterion to the wavelet energy computed over two regions. In a nutshell, we compute the wavelet energy of synthesized power for each pixel in the two regions and for a number of pol states, much in the same way as we did for the WASP. Then we compute the within region and between regions scatter matrices, and build a graph of the Fischer separability as a function of pol state. Eventually the graph can be parametrized by scale into a family of curves.
TEXTURAL CHARACTERIZATION BY WASP ANALYSIS OF THE CENTRAL AFRICA TROPICAL FORESTS

- Y axis represents texture
- Pure volume scattering is not seen from any forest types as peaks in texture are not at 0°.
- Mix of scattering as shift of angles from 0°.
- Very low texture in swamp forests (flooded and non-flooded).
- Secondary forest has more texture because of the diversity of structures (blue areas indicate single bounce and so a mix of mechanisms).
TEXTURAL FISCHER CLASS SEPARABILITY (WASPSEF)

Swamp Forest – Primary Rain Forest

- Y axis is the Fisher Separability.
- Greatest separability at HV
- Low separability between two (values should exceed 1.0)
- Filtering of wavelength variance image increases separability
Institute for Environment and Sustainability
Global Environment Monitoring Unit

BACKSCATTER FISCHER CLASS SEPARABILITY
Swamp Forest – Primary Rain Forest

- Even lower separability if use backscatter and exclude texture.
- Even at a scale factor of 16, the texture measure does not give good separability.
- (based on simple average at scales of 16, 4 and 1).
Within the low density forest, better texture is evident at lower scales.

Better separability at higher scales.

The slope for dense forest is almost linear and so very noise-based.

Sparse forest has more texture and an inversion of trend occurs (at scales of 4 and 5); attributable to variations in structure.
TEXTURAL CHARACTERIZATION OF FORESTS IN AUSTRALIA

WASS Analysis of Dense and Sparse Forests

- At HV polarisation, there is differences between the range (red) and cross range (green) response.
- As structured, differences in texture can be better detected by considering variation in two directions.
TEXTURAL CHARACTERIZATION OF FORESTS IN AUSTRALIA

WASS Analysis of a Deforestation Pattern

- Texture is high at low scales but discrimination is better at a large scale (deforested and not-deforested).
- No inversion is evident and equivalent to pure noise processes.
TEXTURAL CHARACTERIZATION OF FORESTS IN AUSTRALIA

WASS Analysis of a Deforestation Pattern

• At HV polarisations, there is little discrimination in range (red) but more so in the cross range (green).

• Shows sensitivity to the patterns relating to deforestation
È scherzo od è follia
codesta profezia....

Is polarimetric texture
a prank or madness?

Giuseppe Verdi
A Masked Ball
CONCLUSIONS

Results indicate that spatial statistics in PALSAR data can increase, in some cases, class separability in forest mapping problems.

However, since texture measures are derived by local averages, wavelet based texture products need to be generated from high resolution PALSAR imagery (K& C mosaic data may be too coarse)

Experiments using WASP analysis indicate that indeed texture measures based on wavelet frames exhibit dependences on polarization state.

However, assessment of the usefulness of these measures in the passage from supervised analysis to segmentation problems in mapping applications still needs to be addressed in a systematic way and in different thematic contexts.