SAR data processing
Principle and filtering of speckle

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**RADAR:**
RAdio Detection And Ranging

*Emission* of emw
*Reception* backscattered echoes

Road RADAR  
(© US police)

Imaging RADAR PALSAR  
(© NASDA)

US Army
Electromagnetic coherent wave

Coherent wave: *temporal* behaviour

\[
y(t) = A \cos \left( \frac{2\pi}{T} t \right)
\]

\[
y(t) = A \cos \left( \frac{2\pi}{T} t - \varphi \right)
\]

A: amplitude

\[T = \frac{1}{f_0}\]

T: time period

\[\varphi:\text{ phase shift}\]
Electromagnetic coherent wave

Coherent wave: \textit{spatial} behaviour

\[ y(x) = A \cos \left( \frac{2\pi}{\lambda} x \right) \]
\[ y(x) = A \cos \left( \frac{2\pi}{\lambda} x - \varphi \right) \]

\[ \lambda = c \frac{T}{f_0} = \frac{c}{f_0} \]

\begin{itemize}
  \item A: amplitude
  \item \( \lambda \): spatial period = wavelength
  \item \( \varphi \): phase shift
  \item c: light celerity = 3.10^8 \text{ m/s}
\end{itemize}
Coherent wave

\[ y = A \cos \left( \frac{2\pi}{T} t + \frac{2\pi}{\lambda} x + \varphi \right) \]

For given frequency \( f_0 \),

classified by \( A \) and \( \varphi \)
RADAR DATA

SLC product

Amplitude image

Phase image
Coherent Imagery System ➔ Speckle noise

Single pixel value = no meaning

Homogeneous area = statistical distribution
Histogram over an homogeneous area

- **Ideal image**
  - With no noise $\Rightarrow \sigma = 0$

- **Image with little noise**
  - $\Rightarrow \sigma = \text{small}$

- **Image with high noise**
  - $\Rightarrow \sigma = \text{high}$
Histogram over an homogeneous area

Ideal image
With no noise $\Rightarrow \sigma = 0$

Image with little noise $\Rightarrow \sigma =$ small

Image with High noise $\Rightarrow \sigma =$ high

Goal of radar image filtering:

Decrease the standard deviation $\sigma$ (noise) without modify the mean $m$ ($\approx$ radar reflectivity)
Coherent wave

\[ y = A \cos \left( \frac{2\pi}{T} t + \frac{2\pi}{\lambda} x + \phi \right) \]

For given frequency \( f_0 \), characterized by \( A \) and \( \phi \).
A distant vision allows to blur the pointillist effect and see the homogeneous areas

The *average process* effect!!!

Reduces the noise (standard deviation) doesn’t change the average radiometry (mean)
Radar Image

Coherent Imagery System $\Rightarrow$ \textit{Speckle noise}

Single pixel value = no meaning

Homogeneous area = \textit{statistical distribution}
Generating Multilooks Image

Reduce the noise (speckle) = averaging a set of pixels (intensity)

In the spatial domain

Spatial convolution: image * window

9 looks if pixels are not correlated

Example: S1 data – GRDH products: \( \approx 5 \) looks
Intensity image
(from SLC product)

Sète - France: 21.06.2001
RADARSAT FINE 1
INCIDENCE 38°, 4 x9 m
SPATIAL MULTILOOK PROCESSING

3x1 average window

Due to pixels correlation!

6x2 average window

< 3 Look

Sète - France: 21.06.2001

RADARSAT FINE 1
INCIDENCE 38°, 9 x9 m

< 12 Look
SPATIAL MULTILOOK PROCESSING

Sète - France: 21.06.2001 - RADARSAT FINE 1 - INCIDENCE 38°, 9 x 9 m

3x1 average window
< 3 Look
Due to pixels correlation!
< 12 Look

6x2 average window

Airborne photo (www.geoportail.fr)
SAR Image Filtering:

**Goal: estimate** $R \approx \sigma \, ^{\circ}$

Most simple: Box Filtering: $I \rightarrow \text{average} : E(I)$

Advantages: simple + best estimation (*MMSE*) over homogeneous area
Inconvenients: Details lost, fuzzy introduction
Other classical filters: (median, Sigma, math. morph…..): WORST!

$\Rightarrow$ Need to introduce *specific filters taken into account speckle statistics*

Neighbourhood size depends on local scene characteristics
$\Rightarrow$ *Adaptive filters*
Adaptative Filter: Frost, Kuan, Lee,....

homogeneous area: $I_c, I$

$\text{Average}$ over the local window

heterogeneous area: $I_c, I$

Keep the central pixel value ($no\ filtering$)
Radarsat image
Over-sampled fine mode (SGX)
(Aerial base of ‘Salon de Provence’)
Resolution (Single Look complex)
(range x azi.) (m): 6.0 x 8.9

Pixel spacing
(range x azi.) (m): 3.125 x 3.125
Spatial filtering tools test (2/4)

- Frost filter test

**Original image**

**Filtered image**

- **Frost** filter application (analysis window size 9 x 9)
- Over-sampled Radarsat fine mode (SGX)
- ‘Salon de Provence’ : aerial base extract

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Spatial filtering tools test (3/4)

Comparison of different adaptive filters

Original image

average 7x7

Frost 7x7

Gamma-Gamma MAP 7x7

Radarsat 1 extract, fine mode, ‘Salon de Provence’

Simple average computed from the numerical values of neighbor pixels

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Spatial filtering tools test (4/4)

→ influence of the analysis window size

Test of a Gamma-Gamma Map filter over square analysis windows of variable size

Extract Radarsat 1 Fine mode ‘Salon de Provence’
Multilooks image generation

Reduce the noise (speckle) = averaging a set of pixels (intensity)

In the spatial domain

Spatial convolution: image * window

9 looks if pixels are not correlated

Example: S1 – GRDH products: \( \approx 5 \) looks

Loss of spatial information (details)

In the temporal domain

Date 1
Date 2
Date 3
Date 4

4 looks if surface has not changed

Loss of temporal information
Sentinel-1 RADAR BACKSCATTERING IMAGE: Acquisition 2015/03/02

Fontainebleau Forest
Sentinel-1 RADAR BACKSCATTERING IMAGE: Temporal average 2015/03/02 - 2017/01/26

Fontainebleau Forest
GoogleEarth Image

Fontainebleau Forest
Sentinel-1 RADAR BACKSCATTERING IMAGE: Temporal average 2015/03/02-2017/01/26
Sentinel-1 RADAR BACKSCATTERING IMAGE: Temporal average 2015/03/02-2017/01/26
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Sentinel-1 RADAR BACKSCATTERING IMAGE: Acquisition 2015/03/02
Sentinel-1 RADAR BACKSCATTERING IMAGE: Temporal average 2015/03/02-2017/01/26
Speckle filtering: Spatio-temporal domain

Temporal domain

Preservation of spatial res.
Total loss temporal information

Spatio-temporal domain

Small degradation of spatial res.
Small degradation of temporal information
Speckle filtering: Spatio-temporal domain

Given:
- \( N \): acquisitions number (different dates)
- \( J_k \): pixel value of the output (filtered) image
- \( I_k \): pixel value of acquisition \( k \)
- \(< I_k >\): spatial average over a local neighbor. Around \( I_k \)

Equation:
\[
J_k = \frac{< I_k >}{N} \sum_{i=1}^{N} \frac{I_i}{< I_i >} \quad \text{for } k = 1, \ldots, N
\]