Radar Remote Sensing
Henning Skriver

02501 Digital Image Analysis, Vision and Computer Graphics
Fall 2008

Contents of Presentation

- SAR Techniques
  - SAR
  - Polarimetric SAR
  - Interferometric SAR
- Image Processing Techniques
  - Speckle reduction
  - Classification
  - Edge Detection
  - Segmentation
  - Change detection
Contents of Presentation

• SAR Techniques
  • SAR
    • Polarimetric SAR
    • Interferometric SAR
  • Image Processing Techniques
    • Speckle reduction
    • Classification
    • Edge Detection
    • Segmentation
    • Change detection

Earth Observation - Principles
Absorption in the atmosphere
Side-Looking Airborne Radar

Pulse radar
SLAR - azimuth

EMISAR
**ENVISAT**

- **Dimensions**
  - Launch configuration:
    - length 10.5 m
    - envelope diameter 4.6 m
  - In-Orbit configuration:
    - 26m x 10m x 5m

- **Mass**
  - Total satellite 8140 Kg
  - Payload 2050 Kg

- **Power**
  - Solar array power:
    - 6.5 kW (EOL)
  - Average power demand:
    - Sun 3275 watts
    - Eclipse 2870 watts
  - Payload 1700 watts
  - Satellite 3275 watts

- **Orbit**
  - 800 km as ERS, sun synchronous
  - 10:00, i.e. 30 minutes before ERS-2
Surface scattering

Specular reflection  Rough surface scattering
Flooding by radar

[Images showing radar imagery of flooded areas from 2 January 2002 and 16 August 2002]

NOAA AVHRR

[Image showing satellite view of flooded area]
Contents of Presentation

- **SAR Techniques**
  - SAR
  - Polarimetric SAR
    - Interferometric SAR
- **Image Processing Techniques**
  - Speckle reduction
  - Classification
  - Edge Detection
  - Segmentation
  - Change detection
Polarimetric SAR

Scattering matrix

\[
\begin{bmatrix}
S_{vv} & S_{vh} \\
S_{hv} & S_{hh}
\end{bmatrix}
\]
EMISAR C- and L-band Multitemporal

C-band

L-band

March
May
July

Contents of Presentation

• SAR Techniques
  • SAR
  • Polarimetric SAR
  • Interferometric SAR
• Image Processing Techniques
  • Speckle reduction
  • Classification
  • Edge Detection
  • Segmentation
  • Change detection
Interferometric SAR

EMISAR
Interferometric SAR

Elevation mapping

Displacement/velocity
Terrain Motion in L.A., USA: 1992 - today
Contents of Presentation

- SAR Techniques
  - SAR
  - Polarimetric SAR
  - Interferometric SAR
- Image Processing Techniques
  - Speckle reduction
  - Classification
  - Edge Detection
  - Segmentation
  - Change detection

Speckle
Speckle

![Graph 1](image1)

Speckle

![Graph 2](image2)
Contents of Presentation

- SAR Techniques
  - SAR
  - Polarimetric SAR
  - Interferometric SAR
- Image Processing Techniques
  - Speckle reduction
  - Classification
  - Edge Detection
  - Segmentation
  - Change detection

Polarimetric SAR

Scattering matrix

\[
\begin{bmatrix}
S_{vv} & S_{vh} \\
S_{hv} & S_{hh}
\end{bmatrix}
\]
EMISAR C- and L-band Multitemporal

C-band

EMISAR L-band Multitemporal

Correlation coefficient

Phase difference

March  May  July
Polarimetric SAR - pdf’s

Scattering matrix

\[
S = \begin{bmatrix}
S_{hh} & S_{hv} \\
S_{vh} & S_{vv}
\end{bmatrix}
\]

Covariance matrix

\[
X = \begin{bmatrix}
S_{hh}S_{hh} & S_{hh}S_{hv} & S_{hh}S_{vv} \\
S_{hv}S_{hh} & S_{hv}S_{hv} & S_{hv}S_{vv} \\
S_{vv}S_{hh} & S_{vv}S_{hv} & S_{vv}S_{vv}
\end{bmatrix}
\]

Complex Gaussian

\[
Z \sim \mathcal{N}(0, \Sigma)
\]

\[
u(z) = \frac{1}{\sqrt{|\Sigma|}} \exp\left(-\frac{1}{2} z^* \Sigma^{-1} z \right)
\]

Complex Wishart

\[
X \sim \mathcal{W}_C(p, N, \Sigma)
\]

\[
w(x) = \frac{1}{\Gamma_p(N)} |\Sigma|^{N-p} \exp\left(-\frac{1}{2} x^* \Sigma^{-1} x \right)
\]

Gamma

\[
l \sim \Gamma(N, \beta)
\]

\[
v(I) = \frac{1}{\Gamma(N)} |\beta|^{N/2} \exp\left(-\frac{1}{2} \beta I \right)
\]

Complex Wishart classification

Multidimensional ML classification

\[
\hat{u} = [u_1, u_2, \ldots, u_n]
\]

\[
p(u) = \frac{1}{\sqrt{|\Sigma|}} \exp(-\frac{1}{2} (u - \bar{u}) \Sigma^{-1} (u - \bar{u}))
\]

\[
d_1(u, \text{class}_m) = \frac{1}{2} (\bar{u} - \bar{u}) \Sigma^{-1} (u - \bar{u})
\]

\[
+ \frac{1}{2} \ln |\Sigma| - \ln P(\text{class}_m)
\]

Complex Wishart classification

\[
x = (zz^*)
\]

\[
w(x) = \frac{1}{\Gamma_p(N)} |\Sigma|^{N-p} \exp\left(-\frac{1}{2} x^* \Sigma^{-1} x \right)
\]

\[
d_3(x, \text{class}_m) = d_1(x, \text{class}_m) + n \text{ Tr}(\Sigma^{-1} x)
\]

\[
+ n \ln |\Sigma| - \ln P(\text{class}_m)
\]
Land cover from radar

Contents of Presentation

- SAR Techniques
  - SAR
  - Polarimetric SAR
  - Interferometric SAR
- Image Processing Techniques
  - Speckle reduction
  - Classification
  - Edge Detection
  - Segmentation
  - Change detection
Edge Detection Scheme

What is edge detection?

Statistical test of the hypothesis:

\[ \text{Mean[RED area]} = \text{Mean[BLUE area]}? \]

If hypothesis is rejected: We have an edge!

Test for edge using test statistic \( f \):

- N-S edge:
  \[ E_{NS} = f(X_{11} + X_{12} + X_{13}, X_{23} + X_{33}) \]
- NW-SE edge:
  \[ E_{NWSE} = f(X_{12} + X_{22} + X_{23}, X_{33} + X_{33}) \]
- W-E edge:
  \[ E_{WE} = f(X_{11} + X_{12} + X_{13}, X_{31} + X_{32} + X_{33}) \]
- SW-NE edge:
  \[ E_{SWNE} = f(X_{21} + X_{12} + X_{13}, X_{32} + X_{33} + X_{23}) \]

Edge enhancement and direction:

Is the hypothesis of equal means rejected by 1 of \( E \)’s
**Edge Detection - Gaussian**

Test statistic when pixels are Gaussian distributed:

\[ X_i \sim N(\mu_i, \sigma_i) \]

\[ f(X,Y) = \sum X_i - \sum Y_i \]

**Polarimetric SAR - pdf’s**

**Scattering matrix**

\[ S = \begin{bmatrix}
S_{hh} & S_{hv} \\
S_{vh} & S_{vv}
\end{bmatrix} \]

\[ Z = \begin{bmatrix}
S_{hh} \\
S_{hv} \\
S_{vh} \\
S_{vv}
\end{bmatrix}^T \]

**Covariance matrix**

\[ X = ZZ^* = \begin{bmatrix}
S_{hh}S_{hh} & S_{hh}S_{hv} & S_{hh}S_{vv} \\
S_{hv}S_{hh} & S_{hv}S_{hv} & S_{hv}S_{vv} \\
S_{vh}S_{hh} & S_{vh}S_{hv} & S_{vh}S_{vv} \\
S_{vv}S_{hh} & S_{vv}S_{hv} & S_{vv}S_{vv}
\end{bmatrix} \]

**Gamma**

\[ I \sim G(\alpha, \beta) \]

\[ \nu(I) = \frac{1}{\Gamma(\alpha)\beta^\alpha} I^{\alpha-1} \exp\left(-\frac{I}{\beta}\right) \]
**Edge Detection - Gamma**

<table>
<thead>
<tr>
<th>Test statistic when pixels are Gamma distributed:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_i \in G(N, \beta_i)$</td>
</tr>
<tr>
<td>$f(X, Y) = \sum X_i \sum Y_i$</td>
</tr>
</tbody>
</table>

**Polarimetric SAR - pdf’s**

**Scattering matrix**

$$S = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

$$Z = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}^T$$

**Covariance matrix**

$$X = \begin{bmatrix} S_{hh} & S_{hv} & S_{vh} \\ S_{vh} & S_{vv} & S_{hv} \\ S_{hv} & S_{vh} & S_{vv} \end{bmatrix}$$

**Complex Wishart**

$$X \in W_c(p, N, \Sigma)$$

$$w(x) = \frac{1}{\Gamma(N)^{p/2}|\Sigma|^{N-p/2}} \exp\left[-\text{tr}(\Sigma^{-1}x)\right]$$

**Gamma**

$$I \in G(N, \beta)$$

$$v(I) = \frac{1}{\Gamma(N)|\beta|^{N-1}} \exp\left[-\frac{1}{\beta}\right]$$
Wishart Edge Detector

\[
\begin{array}{ccc}
X_{11} & X_{12} & X_{13} \\
X_{21} & X_{22} & X_{23} \\
X_{31} & X_{32} & X_{33}
\end{array}
\]

Test statistic for complex Wishart pdf

\[
X_i \in W_c(p, N, \Sigma_i)
\]

\[
f(X, Y) = \frac{\sum X^H \sum Y}{\sum X + \sum Y}
\]

EMISAR L-band

HH HV VV
Phase diff. HH VV
Corr. coef. HH VV

180 -180 1 0
Wishart Edge Detector - L-band diagonal

L-band

L-band diagonal

Wishart Edge Det. - L-band az. sym.

L-band

L-band azimuthal symmetric
EMISAR L-band

Contents of Presentation

- SAR Techniques
  - SAR
  - Polarimetric SAR
  - Interferometric SAR
- Image Processing Techniques
  - Speckle reduction
  - Classification
  - Edge Detection
  - Segmentation
  - Change detection
Segmentation

Merge Red and Blue regions if hypothesis of equal means is accepted

Segments for Polarimetric SAR
Azimuthal Symmetric - Diagonal

Contents of Presentation

• SAR Techniques
  • SAR
  • Polarimetric SAR
  • Interferometric SAR

• Image Processing Techniques
  • Speckle reduction
  • Classification
  • Edge Detection
  • Segmentation
  • Change detection
Change Detection

Change has occurred between acq. 1 and acq. 2, if hypothesis of equal means for red and blue areas is rejected.

June 98, XP, L-band       June 99, XP, L-band
Segmentation of 2 images separately

Acquisition 1

Acquisition 2

Cov. matrix $X_1$

Cov. matrix $X_2$
Segmentation of 2 images jointly

Covariance matrix for 2 images:

\[
X = \begin{bmatrix}
X_1 & 0 \\
0 & X_2
\end{bmatrix}
\]

June 98, L-band

June 99, L-band
June 98, L-band

June 98 + 99, L-band

Pixel-based test statistics

Segment-based test statistics
Pixel-based test statistics
Segment-based test statistics

**Freeman and Durden decomposition**
Only double-bounce scattering
DTU - courses

30350 Remote Sensing

30340 Radar and Radiometer Systems