Integration of SAR/InSAR Spectral-based Feature Extraction Procedures with Spectral Decomposition Methods for Scene Classification using TerraSAR-X Data

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Motivation: High resolution scene category indexing, large number of structures visible in urban sites

Non-parametric feature extraction methods
Summary

• Introduction
• Data descriptors
  • Spectral features
  • Spectral components
• Experimental data
• Classification results
• Conclusions
Introduction

Study of value adding processing methods for SLC and interferometric SAR data, for scene classification
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Study of value adding processing methods for SLC and interferometric SAR data, for scene classification

Concept: make use of phase information

Direct Estimation from image spectra

Regularization based estimation + Bayesian Model order selection

Consistency validation
Data descriptors – spectral features

Direct estimation from spectra

Spectral differences

\[ F_{(x,y)}^{(r,a)} = \sum_{r=1}^{M} \sum_{a=1}^{N} (N_{(x,y)}{(r,a)} - N_{(x-1,y)}{(r,a)})^2 \]

\[ C_{(x,y)} = \frac{\sum_{r=1}^{M} \sum_{a=1}^{N} \mid S_{(x,y)}{(r,a)} \cdot t \mid}{\sum_{r=1}^{M} \sum_{a=1}^{N} \mid S_{(x,y)}{(r,a)} \mid} \]

\[ \sum_{r=1}^{Rr} \sum_{a=1}^{Ra} \mid S_{(x,y)}{(r,a)} \mid = 0.85 \cdot \sum_{r=1}^{M} \sum_{a=1}^{M} \mid S_{(x,y)}{(r,a)} \mid \]

\[ m_{(x,y)} = \frac{1}{M \times N} \sum_{r=1}^{M} \sum_{a=1}^{N} \mid S_{(x,y)}{(r,a)} \mid \]

\[ \sigma^2{(x,y)} = \frac{1}{M \times N} \sum_{r=1}^{M} \sum_{a=1}^{N} (\mid S_{(x,y)}{(r,a)} - m{(x,y)} \mid)^2 \]
Data model

The 2-D signal model:

\[ y_{n,m} = \sum_{k=1}^{K} \alpha_k \exp\{j2\pi(f_k n + \tilde{f}_k m)\} + e(n, m) \]

Where
- \( \alpha_k = a_k + jb_k \) complex amplitude of the \( k^{\text{th}} \) sinusoid
- \( f_k, \tilde{f}_k \) unknown frequencies of the \( k^{\text{th}} \) sinusoid
- \( e(n, m) \) 2-D noise

Problem: Estimate the parameters of the sinusoidal signals:
\[ \alpha_k, f_k, \tilde{f}_k \]
Proposed method: RELAX algorithm

Model choice: minimize NLS criterion:

\[ C_2 = \| y(n, \overline{n}) - \sum_{k=1}^{K} \alpha_k \exp\{j2\pi(f_k n + \bar{f}_k \overline{n})\} \|_F^2 \]

Algorithm preparations: if \( \alpha_k \) and \( f_k \) are known, then cost function to be minimized for the \( k \)th sinusoid is:

\[ g_k = \sum_{n=0}^{N-1} | y_k(n, \overline{n}) - \alpha_k \exp\{j2\pi f_k n\} \exp\{j2\pi \bar{f}_k \overline{n}\} |^2 \]

Peak of the 2-D periodogram

\[ (\hat{f}_k, \hat{f}_k) = \arg\max_{f_k, \bar{f}_k} \left| \sum_{n=0}^{N-1} y_k(n, \overline{n}) e^{-j2\pi f_k n} e^{-j2\pi \bar{f}_k \overline{n}} \right|^2 \]

Height of the peak (complex)

\[ \alpha_k = \frac{1}{NN} \sum_{n=0}^{N-1} y_k(n, \overline{n}) e^{-j2\pi f_k n} e^{-j2\pi \bar{f}_k \overline{n}} \]

Data descriptors – spectral components

Spectral Estimation using RELAX

1. $K = 1 \Rightarrow \hat{f}_1, \hat{\alpha}_1$ are obtained from $y(n, \bar{n})$
2. $K = 2 \Rightarrow y_2(n, \bar{n})$ is obtained from $\hat{f}_1, \hat{\alpha}_1$
3. $\hat{f}_2, \hat{\alpha}_2$ are obtained from $y_2(n, \bar{n})$
4. $y_1(n, \bar{n})$ is obtained from $\hat{f}_2, \hat{\alpha}_2$
5. Iterate until practical convergence (cost function doesn't change significantly)
6. $K = 3 \Rightarrow y_3(n, \bar{n})$ is obtained from $\hat{f}_1, \hat{\alpha}_1, \hat{f}_2, \hat{\alpha}_2; \hat{f}_3, \hat{\alpha}_3$ are obtained from $y_3(n, \bar{n})$
7. $y_1(n, \bar{n})$ is obtained from $\hat{f}_3, \hat{\alpha}_3, \hat{f}_2, \hat{\alpha}_2; \hat{f}_1, \hat{\alpha}_1$ are obtained from $y_1(n, \bar{n})$
8. $y_2(n, \bar{n})$ is obtained from $\hat{f}_3, \hat{\alpha}_3, \hat{f}_1, \hat{\alpha}_1; \hat{f}_2, \hat{\alpha}_2$ are obtained from $y_2(n, \bar{n})$
9. Iterate until practical convergence (cost function doesn't change significantly)

.................
Data descriptors – spectral components

*Model order selection. Estimation of number of components*

**AKAIKE Information Criterion**

Estimates the expected Kullback-Leibler information between the model generating the data and a candidate model.

\[
\text{Kullback-leibler Information (distance between models)} \quad \text{Maximized log-likelihood (parameter estimation)}
\]

Model selection: \[ \max_g E_y E_x \left[ \log(g(x | \hat{\theta}(y))) \right] \]

\[ \theta = \text{parameter to be estimated from empirical data } y \]

\[ y = \text{generated from } f(x), X \text{ is a random variable} \]

Log likelihood function for model selection: \[ \log( L(\hat{\theta} | y)) - k \]

**Best Model: Minimum AIC value**

\[ AIC = -2 \log(L(\hat{\theta} | y)) + 2k \]
Methodology

Goal: assess parameter’s capability to discriminate scene classes

Evaluation: Accuracy = (TP+TN) / (TP+TN+FP+FN)
Test Site – Bucharest, Romania

TerraSAR-X High Resolution Spotlight: LAN 130
Experimental data – TSX LAN-130

<table>
<thead>
<tr>
<th>SLC Product type: HS SSC</th>
<th>Interferometric pair</th>
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<tr>
<td>Acquisition date: 30.09.2008</td>
<td>Master: HS SSC</td>
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<tr>
<td>Ground range resolution: 0.8905 m</td>
<td>Acquisition date: 11.10.2008</td>
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<td>Azimuth resolution: 1.1000 m</td>
<td></td>
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<tr>
<td>Nr. of looks: 1</td>
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Frequency of classes in database: dominant classes: tall blocks, green areas, urban fabric, commercial and industrial sites

- Commercial Units
- Construction site
- Continuous urban fabric
- Green urban areas
- Grid
- Industrial
- Large road
- Parking
- Parliament
- Rail
- Round and roundabout
- Sparsely vegetated areas
- Sport field
- Square block
- Stadion
- Tall block
- Tall block 1
- Tall concrete wall
- Very tall building
- Water course and bodies
- Disc. urban fabric

- T S X LAN – 130
Experimental data – TSX LAN-130
1650 SLC patches, 200 x 200 m; reduced interferometric database
Results – Spectral and cepstral parameters

Spectral Centroid, Flux, and Rolloff (azimuth and range)

Mean and variance of first 3 cepstral coefficients
Results – Spectral components

Relax parameter $\alpha_k$ (modulus representation), selection of six random components from the estimated stack
Results – Spectral Components

Reconstructed data from estimated spectral components and original SAR patch

Optimum number of components 30-40
Results – Spectral Components

Reconstructed data from estimated spectral components and original SAR patch

Small number of components: Not the best reconstruction

Optimum number of components: 30-40
Results – Spectral Components

Reconstructed data from estimated spectral components and original SAR patch

Small number of components: Not the best reconstruction

But are they representative for a class?

Optimum number of components: 30-40
Results – Scene Class Recognition

SLC

True Negative Rate indicator
Accuracy indicator

Results – Scene Class Recognition

**SLC – Spectral Features and Spectral Components**

![Graph showing accuracy indicators for spectral features and spectral components](image-url)
Results – Scene Class Recognition

InSAR

True Negative Rate indicator
Results – Scene Class Recognition

InSAR

Accuracy indicator

Accuracy InSAR Spectral features
Results – Scene Class Recognition

SLC+ InSAR

Influence of interferogram spectral features on classification accuracy
Conclusions

• Evaluation of the capability of spectral parameters to discriminate scene classes for complex HR TerraSAR-X data

• Spectral estimation method for high resolution data characterization and reconstruction, based on RELAX algorithm.

• Evaluation of the capability of spectral components to discriminate scene classes for complex HR TerraSAR-X data

• Accuracy of recognition better than 80% for main class training

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