Multitemporal RADARSAT-2 Fine-Beam Polarimetric SAR for Urban Land Cover Mapping

Yifang Ban & Xin Niu
KTH Royal Institute of Technology
Stockholm, Sweden
Introduction

• Urban represents one of the most dynamic areas due to rapid global urbanization
• Remote sensing can provide timely and reliable LULC information required for sustainable planning
• Spaceborne high resolution polarimetric SAR data has become an attractive data source for urban land cover mapping.
Background

• Most of the urban analysis using SAR data often only mapped urban extents or very few urban classes.

• Efficiencies of various PolSAR features and multitemporal data combinations have not been fully investigated for urban mapping.

• Ideal segmentation is usually difficult to obtain on SAR data for object-based approach. Pixel-based approaches without contextual analysis generally lead to “Pepper and salt” results. Traditional contextual analysis often produce over averaged results.
Research Objectives

- Assess various PolSAR features and multitemporal data combinations.
- Evaluate pixel-based contextual classification, object-based classification and hybrid approach.
- Compare different PolSAR distribution models, and integrate multi-models for further improvement.
- Investigate SAR for urban land cover classification: PolSAR or very high resolution single polarization SAR?
Related Papers


Structure of the Research

Introduction: thesis structure

Object-based

- Multitemporal PolSAR Feature Comparisons using SVM and Rules (Paper I)
- Object-based and rule-based approach

Hybrid

- Fusion of fine-beam PolSAR and ultra-fine-beam HH SAR data (Paper V)

Pixel-based

- Contextual approaches
  - Adaptive MRF (Paper II)
  - Modified MPAC (Paper III)
- Contextual SEM with single model
- Model Comparison and Selection (Paper IV)
- Contextual SEM with multi-model
Study Area

Greater Toronto Area (GTA), Ontario, Canada

The major landuse/landcover classes:

- Built-up: high-density built-up areas, low-density built-up areas, Industrial and commercial areas, construction sites, wide roads, streets.
- Vegetation: forests, pastures, parks, golf courses and two types of agricultural crops.
- Water
RADARSAT-2 C-band data:

- **Six-date fine-beam Quad-Pol single look complex products.**
  - Pixel-spacing: range 4.7m; azimuth 5.1m
- **Three-date ultra-fine-beam HH SAR data.**
  - Pixel-spacing: range 1.6 m; azimuth 1.6 m

### Fine-beam PolSAR Data

<table>
<thead>
<tr>
<th>Date</th>
<th>Orbit</th>
<th>Incidence angle range (degree)</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 11 2008</td>
<td>Ascending</td>
<td>40.179~ 41.594</td>
<td>A1</td>
</tr>
<tr>
<td>June 19 2008</td>
<td>Descending</td>
<td>40.215~ 41.619</td>
<td>D1</td>
</tr>
<tr>
<td>July 05 2008</td>
<td>Ascending</td>
<td>40.182~ 41.597</td>
<td>A2</td>
</tr>
<tr>
<td>August 06 2008</td>
<td>Descending</td>
<td>40.197~ 41.612</td>
<td>D2</td>
</tr>
<tr>
<td>August 22 2008</td>
<td>Ascending</td>
<td>40.174~ 41.590</td>
<td>A3</td>
</tr>
<tr>
<td>September 15 2008</td>
<td>Ascending</td>
<td>40.173~ 41.588</td>
<td>A4</td>
</tr>
</tbody>
</table>

### Ultra-fine beam HH SAR Data

<table>
<thead>
<tr>
<th>Date</th>
<th>Orbit</th>
<th>Incidence angle range (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 25 2008</td>
<td>Ascending</td>
<td>30.622~ 32.038</td>
</tr>
<tr>
<td>August 12 2008</td>
<td>Ascending</td>
<td>30.611~ 32.043</td>
</tr>
<tr>
<td>September 05 2008</td>
<td>Ascending</td>
<td>30.606~ 32.023</td>
</tr>
</tbody>
</table>
PolSAR vs. Ultra-Fine C-HH SAR
Object-based Approach
Object-based SVM and Rule-based Approach

Method:
- Object-based SVM
- Rule-based approach using object features and spatial relationships
- Comparison of various PolSAR features
- Comparison of different data combinations

Methodology: Object-based SVM and rule-based approach

Flow chart of multitemporal data fusion combining SVM and rule-based method
Methodology: Object-based SVM and rule-based approach

SVM input vector formed by multitemporal features
SVM and rule-based classification scheme.
Pixel-based Approach
• **Method:**
  - Adaptive markov random field (MRF)
  - Spatially variant Finite Mixture Models (FMM)
  - Stochastic expectation maximum (SEM) algorithm
  - Comparison of the contextual SEM with various PolSAR models and contextual SVM
  - Learning control

Contextual SEM Algorithm

• Method:
  - Modified multiscale pappas adaptive clustering (MPAC)
  - SEM algorithm
  - Combination of adaptive MRF and modified MPAC
  - Comparison of the contextual approaches with SVM

Methodology: Contextual SEM algorithm

The structure of the proposed contextual SEM algorithm:

- Model selection (Paper IV)
- Contextual analysis (Paper II) (Paper III)
- Texture enhancement and rule-based extraction for hybrid approach (Paper V)
**Methodology: Contextual analyses**

MRF gives the prior probability

MPAC estimates the varying class features for the observation probability
Adaptive MRF

(1) Adaptive neighborhood

(2) Adaptive energy function

\[ p(L_s | L_r, r \in \eta_s) = \frac{1}{Z_s} \exp \{ (\beta(1 - b_s) \sum_{r \in \eta_s} \delta(L_s - L_r)) \}. \]

Modified MPAC

\[
p(C_j | l_j) = \max \{ f_{l_j}(C_j | \Theta, \hat{\mu}_{W_{ij}}(l_j)), ..., f_{l_j}(C_j | \Theta, \hat{\mu}_{W_{ij}}(l_j)) \},
\]

if local statistic \( \hat{\mu}_{W_{js}}(l_j) \) exists and is considered reliable, \( \forall s \in \{1, ..., S\} \)

\[
p(C_j | l_j) = f_{l_j}(C_j | \Theta, \hat{\mu}_{W_{ij}}(l_j))
\]

if local statistic \( \hat{\mu}_{W_{js}}(l_j) \) does not exist or is not considered reliable, \( \forall s \in \{1, ..., S\} \)

MPAC gives the multitemporal observation probability using the estimated class features from the multiscale adaptive windows and also the global range.
Model Comparison and Selection

• Method:
  - Contextual SEM
  - Comparison of Various PolSAR models
  - Dictionary-based model selection
  - Rule-based model selection

Scheme of the proposed rule-based model selection
Hybrid Approach
Texture Enhancement and Rule-based Feature Extraction

Method:
- Contextual SEM
- Texture enhancement scheme
- Pixel- and object-based fusion approach
- Comparison of the Fine-beam Polarimetric and Ultra-fine Beam HH SAR Data

Texture enhancement scheme
Results & Discussion
Object-based Approach
Object-based Classification

PolSAR feature comparisons

Comparison of various polarimetric SAR parameters on the ascending (right) and the descending (left) data stack.
Multitemporal Combination Comparisons

The performances of selected date combinations
Pixel-based Approach
Comparison of the Contextual Approaches and SVM

Google earth image

PoISAR Pauli image

adaptive MRF

original MPAC

MPAC+adaptive MRF

SVM
Comparison of the contextual approaches and SVM

Google Map  Pauli image  adaptive MRF  original MPAC  MPAC+adaptive MRF  SVM

Zooming examples in a LD area

Google Map  Pauli image  adaptive MRF  original MPAC  MPAC+adaptive MRF  SVM

Legend: Pasture  Water  Forest  Crop 1  Crop 2  Golf  Cons  Ind  HD  LD  Road
Comparison of Various PolSAR Models

Google Map

Pauli image

G0p

Kp

KummerU

Wishart

LD HD Road Cons. Golf Pasture Water Forest Crop1 Crop2
Effects of the dictionary-based model selection

Overall Accuracy and Kappa for the different dictionaries. G=G0p, K=Kp, U=KummerU, W=Wishart. Unit is in percent.
Effects of the rule-based model selection

Results: Pixel-based approach
- Google Map
- G0p
- Wishart
- G0p + HD_Road Rule
- G0p + LD_Forest

Legend:
- LD
- HD
- Road
- Cons.
- Golf
- Pasture
- Water
- Forest
- Crop1
- Crop2
Hybrid Approach
PolSAR data and C-HH data with and without texture analysis

Google map (a), PolSAR Pauli image (b), and results by the PolSAR (c) and C-HH SAR (d) data without (1) and with (2) texture analysis.
Improvement by the hybrid approach to the pixel-based classification of PolSAR data

Changes of the Producer accuracies (red) and User accuracies (green) from using only contextual SEM to the hybrid approach (with texture analysis and rule-based approach) on the PolSAR data. The solid bar is for the increase, the hollow one is for the decrease.
Results: Hybrid Approach

Google Map

Pauli image

PolSAR using hybrid approach

Legend:
- LD
- HD
- Park
- Ind.
- Cons.
- Street
- Road
- Golf
- Water
- Pasture
- Forest
- Crop1
- Crop2
Comparison of Pixel-, Object-based & Hybrid Approaches
Comparison of the Mapping Approaches

Results: Comparison of the mapping approaches

- Google Map
- Pauli Image
- Contextual SEM
- Contextual SEM+
- Model Selection
- Hybrid approach
- Object-based approach
Comparison of the Mapping Approaches

Results: Comparison of the mapping approaches

The producer (left) and user (right) accuracy

OA: Hybrid (0.76)    Object A234 (0.78)    Object A1234D12 (0.86)
Conclusions & Future research
Conclusions

• The processed Pauli parameters were found effective for detailed urban mapping. And the combination of ascending and descending data with proper time span was found significant in urban land cover mapping using multitemporal PolSAR data.

• The proposed contextual approaches were effective for detailed urban mapping using high resolution PolSAR data. Object-based approaches were found relatively more efficient.

• G0p, Kp and KummerU were generally more effective than Wishart model for detailed urban mapping using high resolution PolSAR data. The proposed rule-based model selection was found more effective than the dictionary-based model selection for urban mapping.

• SAR polarizations have been noticed significance for identifying different urban classes. The proposed hybrid approach could effectively improve the urban mapping results
Future Research

• POLinSAR!

• Further development of hybrid methods for high resolution PolSAR data.

• Investigating effective multi-frequency, and multi-resolution data fusion.