Fusion of SAR and optical data for landcover classification

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Presentation Overview

• Aim and methods
• Ground truth data
• SAR Classification
• Optical Classification
• Fusion
• Conclusions
Aim and method

Aim

• Investigate complementarity of Cosmo-Skymed and Pleiades for landcover classification

Methods

• Simulation of data with airborne sensors
• Feature-based classification for SAR
• Minimum distance classifier for optical
• Use of fuzzy-logic based fusion
Glinska Poljana site

- fertile valley in Croatia surrounded by hills
- one of the test areas within the SMART (Space and airborne Mined Area Reduction Tools) project funded by the European Commission/DG/INFSO
- data acquisition (flight campaign of the German Aerospace Centre, DLR) took place in spring 2002

From http://wikimapia.org
Training set

1. roads (3338 pixels)
2. water (11847 pixels)
3. residential areas (18939 pixels)
4. abandoned agricultural land without trees and shrubs (89250 pixels)
5. fields with vegetation (82145 pixels)
6. trees and shrubs (35430 pixels)
Validation set

1. roads (1846 pixels)
2. water (4103 pixels)
3. residential areas (7148 pixels)
4. abandoned agricultural land without trees and shrubs (84141 pixels)
5. fields with vegetation (52189 pixels)
6. trees and shrubs (48175 pixels)
SAR Classification
Simulated Cosmo-Skymed data

Sensor
E-SAR
Operator
DLR, on DO-228
Frequency/Polarisation
X-band ($\lambda=3\text{cm}$), VV polarisation
Used Data Type
Geocoded amplitude data
Spatial Resolution
1 m
Swath Width on Ground
3 km
SAR classification overview

Method: *Feature-based supervised classification*

1. **SAR Image**
2. **Line Detector**
3. **Speckle Reduction**
4. **GLCM**
5. **Haralick Texture Images**
6. **Logistic Regression**
7. **First classification image**
8. **Spatial operator and class merging**
9. **Final Classification Image**
Feature Images

Line Detector Results
- Dark Lines
- Bright Lines

Images of Haralick texture parameters
- Speckle Reduced Amplitude image

- Contrast
- Correlation
- Cluster Prominence
- Cluster Shade
- Energy

- Entropy
- Homogeneity
- Maximum
- Moving Coeff.
- Variance

(10x10 window, dx=1, dy=1)
Feature fusion and classification by logistic regression (LR)

Logistic Regression

Finds an optimal combination of features for detecting a given class, based on the learning set:

\[
p_{x,y}(\text{TgtClass} \mid \vec{F}) = \frac{\exp\left(\beta_0 + \sum_{i=1}^{N} F_i(x, y) \beta_i\right)}{1 + \exp\left(\beta_0 + \sum_{i=1}^{N} F_i(x, y) \beta_i\right)}
\]

- *Implicit feature selection* by using step-wise optimisation method for finding \( \beta_i \) s.
- Combination of detection images into classification
# Feature selection by LR

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<td>x</td>
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<td>x</td>
<td>x</td>
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<td>x</td>
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<td>5</td>
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<td></td>
<td>x</td>
<td>x</td>
<td>3</td>
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<tr>
<td>Fields With Veg.</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td></td>
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<td>Forests</td>
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<td></td>
<td></td>
<td></td>
<td>x</td>
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</table>
First SAR classification image
Spatial operator & class merging

Improve classification by (ad hoc) spatial reasoning

- Select « buildings » next to shadow
- Rivers next to buildings become shadows

Class Merging

- Merge AbanNoTS+BareSoil

Legend:
- Roads
- Water
- Buildings
- AbanNoTS
- Bare Soil
- Fields with Veg
- Forests
- Shadows

First classification image

Final Classification Image
Final SAR classification

- Roads
- Water
- Buildings
- AbanNoTS
- Fields with Veg
- Forests
- Shadows
Optical Classification
Pleiades vs. Daedalus

Panchromatic (PA) – 0.7m resolution
Blue (B0), green (B1), red (B2) and near infrared (B3) – 2.8m resolution

Daedalus multispectral scanner has 12 individual channels of data, including the following wavelengths:

- Band 1: 0.42 - 0.45 \( \mu \)m
- Band 2: 0.45 - 0.52 \( \mu \)m
- Band 3: 0.52 - 0.60 \( \mu \)m
- Band 4: 0.605 - 0.625 \( \mu \)m
- Band 5: 0.63 - 0.69 \( \mu \)m
- Band 6: 0.695 - 0.75 \( \mu \)m
- Band 7: 0.76 - 0.90 \( \mu \)m
- Band 8: 0.91 - 1.05 \( \mu \)m
- Band 9: 1.55 - 1.75 \( \mu \)m
- Band 10: 2.08 - 2.35 \( \mu \)m
- Band 11: 8.5 - 13.0 \( \mu \)m
- Band 12: Band 11 with x0.5 or x2 gain

Daedalus data used here have spatial resolution of 1 m and were acquired at latitude of 300 m.

Classification results – ch2

1. roads
2. water
3. residential areas
4. abandoned agricultural land without trees and shrubs
5. fields with vegetation
6. trees and shrubs
Classification results – ch3
Classification results – ch5

- 1 roads
- 2 water
- 3 residential areas
- 4 abandoned agricultural land without trees and shrubs
- 5 fields with vegetation
- 6 trees and shrubs
Classification results - SAR

1. roads
2. water
3. residential areas
4. abandoned agricultural land without trees and shrubs
5. fields with vegetation
6. trees and shrubs
Fusion
Fusion strategy: fuzzy fusion

• First step:
  – weighted maximum of the classifiers for each class
  – weights estimated from the confusion matrices obtained using the training set
  – decision making using maximum rule
  – fast and simple

• Second step:
  – spatial regularization
  – regional filters (fuzzy fusion of the neighbouring pixels)
## Classification results

### Daedalus & SAR, 6 classes

*(overall accuracy) & producer / user accuracy per class, validation data*

<table>
<thead>
<tr>
<th>Class</th>
<th>Daedalus</th>
<th>X-SAR (0.59)</th>
<th>fusion2 [fusion1 &amp; SAR] (0.77)</th>
<th>fusion12 [each ch and SAR] (0.82)</th>
<th>fusion3 [each ch, barw and SAR] (0.83)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (roads)</td>
<td>0.80 / 0.28</td>
<td>0.86 / 0.28</td>
<td>0.87 / 0.28</td>
<td>0.86 / 0.28</td>
<td>0.68 / 0.55</td>
</tr>
<tr>
<td>2 (water)</td>
<td>0.22 / 0.03</td>
<td>0.63 / 0.05</td>
<td>0.51 / 0.03</td>
<td>0.22 / 0.03</td>
<td>0.08 / 0.03</td>
</tr>
<tr>
<td>3 (residential areas)</td>
<td>0.30 / 0.32</td>
<td>0.51 / 0.13</td>
<td>0.56 / 0.05</td>
<td>0.93 / 0.90</td>
<td>0.94 / 0.91</td>
</tr>
<tr>
<td>4 (abandoned agr. areas without trees or shrubs)</td>
<td>0.37 / 0.57</td>
<td>0.51 / 0.05</td>
<td>0.56 / 0.05</td>
<td>0.74 / 0.82</td>
<td>0.81 / 0.89</td>
</tr>
<tr>
<td>5 (fields with vegetation)</td>
<td>0.59 / 0.58</td>
<td>0.86 / 0.78</td>
<td>0.66 / 0.78</td>
<td>0.76 / 0.79</td>
<td>0.81 / 0.80</td>
</tr>
<tr>
<td>6 (trees and shrubs)</td>
<td>0.75 / 0.80</td>
<td>0.88 / 0.83</td>
<td>0.58 / 0.55</td>
<td>0.89 / 0.84</td>
<td>0.88 / 0.86</td>
</tr>
</tbody>
</table>
Daedalus fusion (fusion1)
Fusion of Daedalus fusion1 and SAR (fusion2)
Fusion of each Daedalus band and SAR (fusion12)
Classification results – fusion3
Confusion matrix for fusion12

<table>
<thead>
<tr>
<th>Number of pixels</th>
<th>classification results</th>
<th></th>
<th>ground truth</th>
<th></th>
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<td>Aban.</td>
<td>Fields</td>
<td>Trees</td>
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<td>Roads</td>
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<td>8</td>
<td>3620</td>
<td>12</td>
<td>3</td>
<td>0</td>
<td></td>
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<tr>
<td>Water</td>
<td>0</td>
<td>3849</td>
<td>306</td>
<td>3</td>
<td>10</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Resid.</td>
<td>12</td>
<td>65</td>
<td>2902</td>
<td>4349</td>
<td>1920</td>
<td>269</td>
<td></td>
</tr>
<tr>
<td>Aban.</td>
<td>7</td>
<td>64</td>
<td>133</td>
<td>68134</td>
<td>5894</td>
<td>2011</td>
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</tr>
<tr>
<td>Fields</td>
<td>128</td>
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<td>54</td>
<td>7110</td>
<td>42504</td>
<td>3516</td>
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<tr>
<td>Trees</td>
<td>108</td>
<td>117</td>
<td>133</td>
<td>4533</td>
<td>1858</td>
<td>42322</td>
<td></td>
</tr>
</tbody>
</table>

a great part of ground-truth residential areas are classified as roads (and a great part of pixels classified as roads are residential areas in reality)

a great part of pixels classified as residential areas are abandoned agricultural areas without trees and shrubs in reality
### Fusion12, confusion matrix (number of pixels)

<table>
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<th>Roads</th>
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<th>Resid.</th>
<th>Aban.</th>
<th>Fields</th>
<th>Trees</th>
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<tbody>
<tr>
<td>Roads</td>
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<td>8</td>
<td>3620</td>
<td>12</td>
<td>3</td>
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<tr>
<td>Water</td>
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<td>306</td>
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<td>57</td>
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<tr>
<td>Resid.</td>
<td>12</td>
<td>65</td>
<td>2902</td>
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<td>269</td>
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<tr>
<td>Aban.</td>
<td>7</td>
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<td>133</td>
<td>68134</td>
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<td>2011</td>
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<td>Fields</td>
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<td>54</td>
<td>7110</td>
<td>42504</td>
<td>3516</td>
</tr>
<tr>
<td>Trees</td>
<td>108</td>
<td>117</td>
<td>133</td>
<td>4533</td>
<td>1858</td>
<td>42322</td>
</tr>
</tbody>
</table>

### Fusion3, confusion matrix (number of pixels)

<table>
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<tr>
<th>Class</th>
<th>Roads</th>
<th>Water</th>
<th>Resid.</th>
<th>Aban.</th>
<th>Fields</th>
<th>Trees</th>
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<td>12</td>
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<td>Water</td>
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<td>298</td>
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<tr>
<td>Resid.</td>
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<td>60</td>
<td>5532</td>
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<td>118</td>
<td>131</td>
<td>4533</td>
<td>1858</td>
<td>42322</td>
</tr>
</tbody>
</table>
Classification results – class 1 (roads)

Daedalus fusion
Classification results – class 2 (water)

Daedalus and SAR fusion
Classification results – class 3
(residential areas)
Daedalus and SAR fusion
Classification results – class 4
(abandoned agricultural areas without trees or shrubs)
Classification results – class 5 (fields with vegetation)
Classification results – class 6 (forests and shrubs)
Qualitative Conclusions

• for each particular class, both Daedalus fusion as well as overall fusion results are mostly better than the best single classifier

• good results at the first fusion step already

• noisy aspect suppressed by regularization

• adding knowledge would further improve results (SMART experience)