Mapping road traffic conditions using high resolution satellite images

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Collaborators:
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Norwegian Space Centre (Norsk Romsenter)
Outline

► Background
► Algorithm
  ▪ Masks
  ▪ Segmentation
  ▪ Shadow prediction
  ▪ Feature extraction
  ▪ Classification
► Results
► Conclusion
Background

► Road network maintenance and development
► Annual Day Traffic (ADT)
  ▪ statistical tools developed by NR
► Today: induction loops in the road
  ▪ expensive
  ▪ limited geographical coverage
► In the future: automated counts using high resolution satellite images?
Masks

► Road mask
  ▪ manual delineation
  ▪ automatic generation
    ◦ buffer mask from midline vectors
    ◦ rectification (manually selected reference points)

► Vegetation mask
  ▪ roadside tree canopy and vegetation between lanes
  ▪ NDVI + Otsu
Segmentation

Image histogram of masked panchromatic image
Segmentation

- Segmentation of dark segments:
  - strict threshold: Otsu \([I_{\text{min}}, \mu - \sigma]\)
  - loose threshold: Otsu \([I_{\text{min}}, \mu - 0.5\sigma]\)

- Segmentation of bright segments:
  - loose threshold: Otsu \([\mu + \sigma, I_{\text{max}}]\)
  - strict threshold: \(\mu + 3\sigma\)
Segmentation

Segmentation thresholds
Segmentation examples
Vehicle shadows
Prediction of vehicle shadows

- A dark segment that
  1) overlaps the expected shadow zone of a bright segment
  2) is close in distance to the bright segment

  is considered to be a vehicle shadow

- To predict this we need
  - a segmented image containing dark segments
  - a segmented image containing bright segments
  - a distance map to bright objects
  - a structure element representing the expected shadow zone
Sun azimuth relative to image
Direction of shadow

- EW
- S
- N
- local azimuth
Sun elevation
Length of shadow

- Sun elevation
- Vehicle height
- Shadow length
Predicting shadows 1

Dilate bright segments with expected shadow zone

Subtract bright segments
For each dark segment:

- If distance to bright segment is small & it overlaps an expected shadow zone

Otherwise

- Shadows

- Vehicles

- Expected shadow zones

- Distance to bright segments
Classification

- Maximum likelihood
  - multivariate Gaussian distribution
  - general class covariance matrices

- Six classes:
  - Bright car
  - Dark car
  - Bright truck
  - Bright vehicle fragment
  - Vehicle shadow
  - Road mark - arrow
# Region features

<table>
<thead>
<tr>
<th>Preclassification</th>
<th>Main classification</th>
<th>Post classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule based</td>
<td>Maximum likelihood</td>
<td>Rule based</td>
</tr>
<tr>
<td>► Area</td>
<td>► Intensity mean</td>
<td>► Distance to</td>
</tr>
<tr>
<td>► Elongation</td>
<td>► Gradient mean (Sobel)</td>
<td>nearest shadow</td>
</tr>
<tr>
<td></td>
<td>► Intensity standard deviation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>► Length of bounding box</td>
<td></td>
</tr>
<tr>
<td></td>
<td>► 1st Hu moment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>► Spatial spread ($\frac{\mu_{20} + \mu_{02}}{\mu_{00}}$)</td>
<td></td>
</tr>
</tbody>
</table>

A small bright segment close to a shadow is more likely a vehicle fragment (as opposed to a road mark).
Illustration of features

- Masked panchromatic image
- Length
- Mean intensity
- 1st Hu moment
- Spatial spread
- Intensity standard deviation
- Mean gradient
Classification results

Classification rate: 70.6%

Classification rate not including reject segments: 88.7%

Two-class (car/no car) classification rate: 81.0%

<table>
<thead>
<tr>
<th>Given label</th>
<th>Bright vehicle</th>
<th>Dark vehicle</th>
<th>Vehicle shadow</th>
<th>Road marking</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>True label</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Bright vehicle</td>
<td>96</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>107</td>
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<tr>
<td>Dark vehicle</td>
<td>0</td>
<td>59</td>
<td>7</td>
<td>0</td>
<td>66</td>
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<tr>
<td>Vehicle shadow</td>
<td>0</td>
<td>10</td>
<td>62</td>
<td>0</td>
<td>72</td>
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<tr>
<td>Road marking</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Reject</td>
<td>11</td>
<td>20</td>
<td>22</td>
<td>10</td>
<td>63</td>
</tr>
<tr>
<td>SUM</td>
<td>107</td>
<td>89</td>
<td>91</td>
<td>23</td>
<td>310</td>
</tr>
</tbody>
</table>
Validation

- Counts from road stations:
  - # of cars passing per hour
  - average speed
  - extract sub image that cover a road segment in the vicinity of the station
  - estimate # of vehicles that "should" appear in the image (based on # of vehicles per hour + speed + length of road)

- Manual counts:
  - two persons have independently counted vehicles in the images

- Automatic counts in image:
  - using the described methods
## Validation results

<table>
<thead>
<tr>
<th>Location</th>
<th>Length of road segment (m)</th>
<th>Time of image acquisition (UTC)</th>
<th>Manual count in image</th>
<th>Predicted # of vehicles in image (from in-road counts 10-11 UTC)</th>
<th>Predicted # of vehicles in image (from in-road counts 11-12 UTC)</th>
<th>Number of objects classified as vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sennalandet</td>
<td>19 718</td>
<td>10:35</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>Kristiansund # 1</td>
<td>1 055</td>
<td>10:56</td>
<td>22</td>
<td>25</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Kristiansund # 2</td>
<td>5 775</td>
<td>10:56</td>
<td>32</td>
<td>27</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td>Østerdalen north</td>
<td>31 779</td>
<td>10:39</td>
<td>44</td>
<td>51</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Eiker</td>
<td>7 836</td>
<td>10:42</td>
<td>57</td>
<td>57</td>
<td>67</td>
<td>39</td>
</tr>
<tr>
<td>Sollihøgda # 1</td>
<td>7 819</td>
<td>10:32</td>
<td>63</td>
<td>58</td>
<td>61</td>
<td>64</td>
</tr>
<tr>
<td>Sollihøgda # 2</td>
<td>6 139</td>
<td>10:32</td>
<td>30</td>
<td>38</td>
<td>41</td>
<td>26</td>
</tr>
</tbody>
</table>
Challenges

► Different lighting conditions
► The hypothesis about the image histogram does not hold anymore
Challenges
Reject segments

- Heterogeneous group of segments that do not belong to any of the classes, e.g.:
  - tree shadows
  - other types of road marks
  - part of bridges, signs, roundabouts, etc.
Conclusion

- The majority of vehicles that are correctly segmented are also correctly classified.
- The segmentation routine should be improved in order to find even vehicles with low contrast.
- Additional features and context based information should be examined in order to reject non-vehicle segments.
The SatTrafikk project

- Started in 2006 with the ESA (European Space Agency) project Road Traffic Snapshot, Institute of Transport Economics (Transportøkonomisk Institutt) also involved
- SatTrafikk: 2007 - ?
- Main utility: estimate Annual Day Traffic, used by **Norwegian Public Roads Administration**, especially useful for (country side) high ways where in-road counts are expensive
- Software developed by NR
- Funding: **Norwegian Space Centre**
Thank you for the attention!