Automated Surface Feature Identification in Mars Orbital Images

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Surface Features of Interest

Dark slope streaks

Dust devil tracks

> 50 Terabytes
Dark Slope Streaks

Image credit: MOC

June 12, 2000

April 12, 2002

New dark slope streaks
Landmark-Based vs. Pixel-Based

Dark slope streak

Dark slope streak
Landmark-Based Change Detection

1. Compute salience map
2. Detect landmarks
3. Extract attributes
4. Classify landmarks
5. Compare landmark sets (change detection) (in progress)
Salient Landmark Detection

- Compute salience of a region
  - How unusual is it?
  - Can we recognize it later?

- Benefits
  - Summarize a region with a few key landmarks
  - Recognize same region later without pixel-level registration
  - Not restricted to previously known types of features
  - Detect changes as new, vanished, or altered landmarks

Summer Triangle: Deneb, Vega, and Altair
Salience

- Ideal: salience(region) = how interesting the region is
- Proxies
  - Intensity histogram: analyze distribution of pixel values
  - Covariance matrix: analyze spatial properties of region
- Salience = interest with respect to a reference (larger region, full image)
1. Intensity Histograms

- Region = vector of intensity histogram counts (no spatial)
### Histogram Salience Computation

- **Entropy**: How heterogeneous is the window?

  \[
  \text{salience}(w) = H(w) = - \sum_i w(i) \log w(i)
  \]

- **KL-divergence**: How much does a window stand out from the full image, or from a context window?

  \[
  \text{salience}(w_1) = D_{KL}(w_1||w_2) \sum_i w_1(i) \log \frac{w_1(i)}{w_2(i)}
  \]
2. Covariance Descriptors

- How are image attributes related? (no intensity)
- Attributes: Haar filter values over 3x3 areas
  - Boxcar average
  - Center-surround
  - Horizontal and vertical gradient
  - Horizontal and vertical bar
Covariance Salience Computation

- Region = matrix of covariance values
- Covariance matrix: each attrib. vs. each other attrib.
- Distance between two covariance matrices (Tuzel et al., 2006):

\[
salience(w_1) = \rho(C_1, C_2) = \sqrt{\sum_i \ln^2 \lambda_i(C_1, C_2)}
\]

- Salience of a region:
  - Distance between region and full image
  - Distance between region and context window
Salience Maps

Entropy  KL-divergence  Covariance

Window size = 20 x 20 pixels
Salience Maps

- Use a threshold to identify landmarks

Entropy
KL-divergence
Covariance

Window size = 20 x 20 pixels
Evaluating Landmark Detection

- True positives: pixels in manual and detected landmarks
- False positives: pixels in detected but not manual landmarks

**Entropy**

<table>
<thead>
<tr>
<th>TP</th>
<th>21%</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP</td>
<td>8%</td>
</tr>
</tbody>
</table>

**KL-divergence**

<table>
<thead>
<tr>
<th>TP</th>
<th>71%</th>
</tr>
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<tbody>
<tr>
<td>FP</td>
<td>6%</td>
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</table>

**Covariance**

<table>
<thead>
<tr>
<th>TP</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP</td>
<td>14%</td>
</tr>
</tbody>
</table>
Increasing the Salience Threshold

(Animation)
ROC Curves

Best performance at upper left corner
(100% TP, 0% FP)

Dust Devil Tracks

Dark Slope Streaks

MOC R0201153

MOC E0100578
Landmark Classification

Annotated Images

Training Examples
(114, 33, 1.2) Streak
(839, 87, 5.3) Devil
(206, 110, 15.7) Crater
...

New Image

New Examples
(627, 122, 7.3) ?
(922, 80, 8.9) ?
(739, 154, 8.8) ?
...

Machine Learning

Classifier

Machine Learning

Extract attributes
Classify landmarks

Dark Slope Streak
Dust Devil Track
Crater

Landmark Attributes
Area (size)
Perimeter
Mean intensity (0-255)
Std dev. of intensity
Ellipse-fit
Eccentricity
Orientation
Fit error
Roughness
Landmark Classification Models

- Based on 767 manual annotations
  - Dark slope streaks (70)
  - Dust devil tracks (656)
  - Craters (41)

If conf < 0.98, mark “unknown”

Most useful feature: eccentricity

<table>
<thead>
<tr>
<th>Classifier</th>
<th>Accuracy</th>
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</thead>
<tbody>
<tr>
<td>Neural Network</td>
<td>95%</td>
</tr>
<tr>
<td>Decision Tree</td>
<td>94%</td>
</tr>
<tr>
<td>Support Vector Machine</td>
<td>91%</td>
</tr>
</tbody>
</table>
Landmark Classification Results

MOC R0701606
Salience: KL-divergence in 20x20 window, from 200x200 window

Crater

Streaks

MOC R0701606
Salience: KL-divergence in 20x20 window, from 200x200 window
Next: Change Detection

- State of the art: pixel-based registration and differencing
- Regional landmark graphs: landmarks (with class and features) plus relative position
- Ellipse-fit projections can enable recognition even between images from different instruments
- Expect reduction in runtime and in false detections
Summary

- **Landmark-based image analysis**
  - Characterize semantic content of image (gullies, streaks, etc.)
  - Use histograms or covariance descriptors, statistical measures of distance/salience

- **Benefits**
  - Support content-based archive searches
  - Enable faster change detection

- **Thank you! Any questions?**

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