Texture-Aware Superpixel Segmentation
Large data $\rightarrow$ high computational times
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- Regular multi-resolution:
  Decompose the image into regular blocks
Introduction

Large data $\rightarrow$ high computational times $\rightarrow$ Dimension reduction

- **Regular multi-resolution:**
  Decompose the image into regular blocks

- **Superpixels (since [Ren and Malik, 2003]):**
  Local grouping of pixels with homogeneous colors
Desired properties of superpixel methods:

- Relatively fast to compute ✓
- Limited parameter settings ✓
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- Relatively fast to compute ✓
- Limited parameter settings ✓
- Both accurate and regular superpixels ~

[Chen et al., 2017]
Introduction

Desired properties of superpixel methods:

- Relatively fast to compute ✓
- Limited parameter settings ✓
- Both accurate and regular superpixels ～

→ Irregular borders on textured regions

[Chen et al., 2017]  [Chen et al., 2017]
Robustness of state-of-the-art methods

What about textured images?

→ All state-of-the-art methods severely fail at clustering textures
Robustness of state-of-the-art methods

What about textured images?

→ Even with manual regularity tuning, no explicit consideration of texture information
Robustness of state-of-the-art methods

What about textured images?

→ Even with manual regularity tuning, no explicit consideration of texture information

→ TASP: Texture-Aware SuperPixel segmentation method
1 Introduction

2 The SLIC method

3 The proposed TASP method

4 Results

5 Conclusion
Simple Linear Iterative Clustering (SLIC) [Achanta et al., 2012]

Distance between a pixel $p$ and a superpixel $S_k$:

$$D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})$$

- $F_p = [l_p, a_p, b_p]$ color in the CIELab space
- $X_p = [x_p, y_p]$ position
- $F_{S_k}, X_{S_k}$ average on pixels $\in S_k$
- $m$ regularity parameter

Constrained K-means iterative refinement

Block init. $s \times s$
Simple Linear Iterative Clustering (SLIC) [Achanta et al., 2012]

Distance between a pixel $p$ and a superpixel $S_k$:

$$D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})m$$

$F_p = [l_p, a_p, b_p]$ color in the CIELab space

$X_p = [x_p, y_p]$ position

$F_{S_k}, X_{S_k}$ average on pixels $\in S_k$

$m$ regularity parameter
The SLIC method

Distance between a pixel $p$ and a superpixel $S_k$:

$$D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})^m$$

Limitations:

- Global regularity parameter $\rightarrow$ irregular borders with low $m$ / inaccurate borders with high $m$.
- Only local pixel color considered $\rightarrow$ not robust to texture.
The SLIC method

Distance between a pixel $p$ and a superpixel $S_k$:

$$D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})m$$

Limitations:

- Global regularity parameter $\rightarrow$ irregular borders with low $m$ / inaccurate borders with high $m$.
- Only local pixel color considered $\rightarrow$ not robust to texture.

$m = 200$

$m = 500$
The TASP method

- Automatic adaptation of the regularity parameter:

\[ m_k = m \exp(\sigma(F_p \in S_k)^\beta) \]

SLIC [Achanta et al., 2012]
The TASP method

- Automatic adaptation of the regularity parameter:

\[ m_k = m \exp \left( \frac{\sigma(F_{p \in S_k})}{\beta} \right) \]

SLIC [Achanta et al., 2012]
The TASP method

- Automatic adaptation of the regularity parameter:

\[ m_k = m \exp \left( \frac{\sigma(F_p \in S_k)}{\beta} \right) \]

SLIC [Achanta et al., 2012]

Ponderation with feature variance within superpixels:

\[ D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})m \]

SLIC clustering distance [Achanta et al., 2012]:

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Texture-Aware Superpixel Segmentation
The TASP method

- Automatic adaptation of the regularity parameter:

\[ m_k = m \exp \left( \frac{\sigma(F_p \in S_k)}{\beta} \right) \]

TASP clustering distance:

\[ D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})m_k \]
Pixel to superpixel texture homogeneity term:

→ Bench of filters?

Prior definition of filters
Cannot be precisely averaged over a superpixel
Pixel to superpixel texture homogeneity term:

→ *Bench of filters?*

*Prior definition of filters*
*Cannot be precisely averaged over a superpixel*

→ *Patch-based distance?*

*No complex texture classification approach*
*Remains in the same feature space than pixel to superpixel distances*
The TASP method

- Pixel to superpixel texture homogeneity term:
  Which patches to compare?
    → Patch on the superpixel barycenter?
      \[ \text{Not representative of the texture content} \]
The TASP method

- Pixel to superpixel texture homogeneity term:

  Which patches to compare?
  
  → Patch on the superpixel barycenter?

    *Not representative of the texture content*

  → Nearest neighbor (NN) matching within the superpixel?

    *Ability to find only similar texture patterns*
    
    *Fast selection of $N$ similar patches with PatchMatch [Barnes et al., 2009]*
The TASP method

- Pixel to superpixel texture homogeneity term:
  
  Which patches to compare?
  
  → Patch on the superpixel barycenter?
  
  *Not representative of the texture content*
  
  → Nearest neighbor (NN) matching within the superpixel?
  
  *Ability to find only similar texture patterns*
  
  *Fast selection of $N$ similar patches with PatchMatch* [Barnes et al., 2009]

Texture homogeneity term:

$$d_{\text{texture}}(p, S_k) = \frac{1}{N} \sum_{p_k \in \mathcal{K}_P} \frac{1}{n} \| F_{\text{P}(p)} - F_{\text{P}(p_k)} \|_2$$
The TASP method

- Pixel to superpixel texture homogeneity term:

  \[ d_{\text{texture}} \]

  does not guarantee texture unicity within superpixels
The TASP method

- Pixel to superpixel texture homogeneity term:

\[ d_{\text{unicity}} \]

\[ d_{\text{unicity}} \] does not guarantee texture unicity within superpixels

\[ \rightarrow d_{\text{unicity}} \] forces the selection of patches \( p_k \) close to the superpixel barycenter:

\[
d_{\text{unicity}}(p, S_k) = 2 \cdot \frac{1}{N} \sum_{p_k \in \mathcal{K}_p} \left( 1 - \exp \left( -\frac{\|X_{p_k} - X_{S_k}\|^2}{s^2} \right) \right)
\]
The TASP method

- Pixel to superpixel texture homogeneity term:

\[
\begin{align*}
\text{SLIC [Achanta et al., 2012]} & \quad \text{TASP w/ } d_{\text{texture}} & \quad \text{TASP w/ } d_{\text{texture}} + d_{\text{unicity}} \\
\end{align*}
\]

\[d_{\text{texture}} \text{ does not guarantee texture unicity within superpixels}\]

\[\rightarrow d_{\text{unicity}} \text{ forces the selection of patches } p_k \text{ close to the superpixel barycenter:}\]

**Spatial distance on selected patches:**

\[
d_{\text{unicity}}(p, S_k) = 2 \cdot \frac{1}{N} \sum_{p_k \in \mathcal{K}_p} \left( 1 - \exp \left( -\frac{\|X_{p_k} - X_{S_k}\|_2^2}{s^2} \right) \right)
\]

**SLIC clustering distance [Achanta et al., 2012]:**

\[
D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})m
\]
The TASP method

- Pixel to superpixel texture homogeneity term:

$d_{\text{texture}}$ does not guarantee texture unicity within superpixels

$\rightarrow d_{\text{unicity}}$ forces the selection of patches $p_k$ close to the superpixel barycenter:

Spatial distance on selected patches:

$$d_{\text{unicity}}(p, S_k) = 2 \frac{1}{N} \sum_{p_k \in \mathcal{K}_p} \left( 1 - \exp \left( - \frac{\|X_{p_k} - X_{S_k}\|^2}{s^2} \right) \right)$$

Final TASP clustering distance:

$$D(p, S_k) = d_{\text{color}}(F_p, F_{S_k}) + d_{\text{spatial}}(X_p, X_{S_k})m_k + d_{\text{texture}}(p, S_k) + d_{\text{unicity}}(p, S_k)m_k$$
Results - Qualitative comparison to state-of-the-art

On a very textured synthetic image:

- **Initial image**
- **SLIC** [Achanta et al., 2012]
- **ERGC** [Buyssens et al., 2014]
- **ETPS** [Yao et al., 2015]
- **LSC** [Chen et al., 2017]
- **SNIC** [Achanta et al., 2017]
- **SCALP** [Giraud et al., 2018]
- **TASP**

**mix-Stripes**: dataset of 10 images of size $300 \times 400$ with synthetic stripe textures
Results - Qualitative comparison to state-of-the-art

On a composite natural texture image:

- Initial image
- LSC [Chen et al., 2017]
- SNIC [Achanta et al., 2017]
- SCALP [Giraud et al., 2018]
- TASP

mix-Brodatz: dataset of 100 images of size $300 \times 400$ with natural textures [Brodatz, 1966]
Results - Qualitative comparison to state-of-the-art

On a natural color image:

![Initial image](image1)

LSC [Chen et al., 2017]

SNIC [Achanta et al., 2017]

![Initial image](image2)

SCALP [Giraud et al., 2018]

TASP

**BSD**: dataset of 200 natural color images of size $321 \times 481$ [Martin et al., 2001]
Results - Quantitative comparison to state-of-the-art

**Standard metrics:**
- Superposition with several objects: ASA
- Contour detection: F-measure

<table>
<thead>
<tr>
<th>Method</th>
<th>mix-Stripes (synthetic textures)</th>
<th>mix-Brodatz (natural textures)</th>
<th>BSD (natural color)</th>
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<tbody>
<tr>
<td></td>
<td>ASA</td>
<td>F</td>
<td>ASA</td>
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<tr>
<td>SLIC [Achanta et al., 2012]</td>
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<td>SCALP [Giraud et al., 2018]</td>
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<td><strong>0.8706</strong></td>
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<td><strong>0.8139</strong></td>
</tr>
</tbody>
</table>

→ Best performances on the three data types with the same parameters
Summary of contributions

- Superpixel method robust to texture
- Generic patch-based texture homogeneity term
- No need for manual regularity setting
- Accurate results on both texture and natural color datasets

Work in progress / Research perspectives

- Improvement of computational time (EUSIPCO 2019)
- Use of advanced texture descriptors
- Application to real data (3D medical, satellite, etc.)
Texture-Aware Superpixel Segmentation

Thank you for your attention

Check for source codes at


