Unsupervised Seabed Segmentation of Synthetic Aperture Sonar Imagery via Wavelet Features and Spectral Clustering

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ABSTRACT

An unsupervised seabed segmentation algorithm for synthetic aperture sonar (SAS) imagery is proposed. Each 2 m × 2 m area of seabed is treated as a unique data point. A set of features derived from the coefficients of a wavelet decomposition are extracted for each data point. Spectral clustering is then performed with this data, which assigns the data points to clusters. This clustering result is then used directly to effect a segmentation of the SAS image into different seabed types. Experimental results on four real, measured SAS images demonstrate the promise of the proposed approach. Importantly, accurate image segmentation results are achieved on the large, challenging images without the aid of any training data or parameter estimation.

Motivation: Performance for mine countermeasure operations are a strong function of seabed type.

Objective: Segment seabed into different types e.g., flat mud, flat sand, sand ripples, rocky, posidonia

Data: Synthetic aperture sonar (SAS) imagery
Collected in Baltic Sea in Spring 2008 by MUSCLE AUV
300 kHz sonar with 60 kHz bandwidth
Image resolution is ~3 cm

Wavelet-based Features: RMS value of the wavelet-coefficient amplitudes at different orientations and scales.
- Rationale: wavelet-coefficient energy will be large when the orientation and scale match the orientation and scale of high-energy texture components in an image block.

Spectral Clustering: Exploits the eigenvectors of a matrix composed of distances between data points to perform clustering.
- Rationale: seabed types change gradually in an image such that the data points of a given type form chain-like structures in feature space.

Define the affinity matrix $A \in \mathbb{R}^{n \times n}$ that expresses the similarity between each pair of data points as

$$A_{ij} = \begin{cases} \exp\left(-\frac{||x_i - x_j||^2}{\sigma}\right), & \text{if } i \neq j; \\ 0, & \text{if } i = j, \end{cases}$$

where $\sigma$ is a constant. Define the diagonal matrix $D$ as $D_{ii} = \sum_{j=1}^{n} A_{ij}$, and form the matrix $L = D^{-1/2}AD^{-1/2}$.

Segmentation Performance

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<td>$k$-means</td>
<td>Spectral Clustering</td>
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| MOMENTS  | 0.6084          | 0.6059          |
| WAVELETS | 0.7628          | 0.8495          |

Unsupervised Seabed Segmentation Results

Green: Flat sand
Yellow: Sand ripples
Blue: Rocky
Orange: Flat mud

IEEE International Conference on Image Processing • Cairo, Egypt • 7-10 November 2009