GEOMIX

Geometry in the mix: geometric methods for non-linear spectral unmixing

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Hyperspectral imagery

Hyperspectral image:

- High number of narrow spectral bands

Spectral mixing

- Low spatial resolution, multiple reflections, intimate mixtures
- Observed spectrum is complex mixture of components within and near pixel’s field of view
- Unmixing: inverts this process
Unmixing delivers:

- Endmember spectra

- Abundance maps

- Possible metadata:
Many problems

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<th>Nonlinear effects</th>
<th>Variability</th>
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<th>Neighbor effects</th>
<th>Validation</th>
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Many models

• Linear mixing model
  - (+) Fast, easy, popular, clear physical interpretation
  - (-) Only for simplest of scenes

• Bilinear mixing models
  - (+) Secondary scattering
  - (-) Physics lacking, hard optimization, interpretation

• Intimate mixing, Radiative Transfer models
  - (+) Powerful for intimate mixtures, physics based
  - (-) Forward model, restricted applicability
Goals

• Physics-based nonlinear models and data-drive methods
  • Easy to use:
    - Model easy to invert and fit to data
    - Parameters have clear physical meaning
  • Allow spectral variability, shadows, neighbor effects
  • Reasonable computational times

• An unmixing validation framework
Multilinear mixing model

- Ray-based approximation of light
- Markov-chain description of interactions
- Assumptions:
  - After each interaction, probability $P$ for further interactions
  - Probability of interacting with a material = abundance
  - Light intensity changes according to endmember reflectance

\[
x = \frac{(1 - P)y}{1 - Py} = \frac{(1 - P) \sum_{i=1}^{p} a_i w_i}{1 - P \sum_{i=1}^{p} a_i w_i}
\]

Multilinear mixing model: neighbor effects

Inclusion of neighbor effects

- Pixel-dependent “neighbor endmember”:
- Secondary illumination: Additional light source
- Adjacency: Additional linear term

\[
x = \frac{(1 - P)(\bar{1} + Q\mathbf{n}_n)\mathbf{y}}{1 - P \left( (1 - Q)\bar{1} + Q^2\mathbf{n}_n \right) \mathbf{y}}
\]
Multilinear mixing model: shadow

• Shadow = no direct illumination. Include by scaling linear term with a shadow parameter in \([0,1]\).

• Ambient light: Include additional light term
• Variability: Library based approach (e.g. MESMA). Allow endmembers to vary per pixel. Select best combination.

• Preliminary results are promising (master thesis)

• Geometrical methods for speeding up search strategy

Validation of spectral unmixing

Validation on several levels:

- Modeled data obtained by using mixing models
- Standard data sets with several levels of ground truth available (e.g. AVIRIS and APEX data)
- New data sets (CRISM data)
- Existing simulated hyperspectral scenes using ray-tracing technology (e.g. Somers et al.)
- New simulated hyperspectral scenes using our own ray-tracer

Unmixing validation initiative:

- Set up by PI and international partner
- Collect, generate (raytracer) and distribute unmixing data sets
- Develop best practices for validation: “How” to validate.
- (Will be) presented at IEEE conferences (past and future), IEEE GRS Magazine (special issue, edited by R. Heylen, M. Parente and J. Kerekes)