An Iterative Method for Hyperspectral Pixel Unmixing Leveraging Latent Dirichlet Variational Autoencoder

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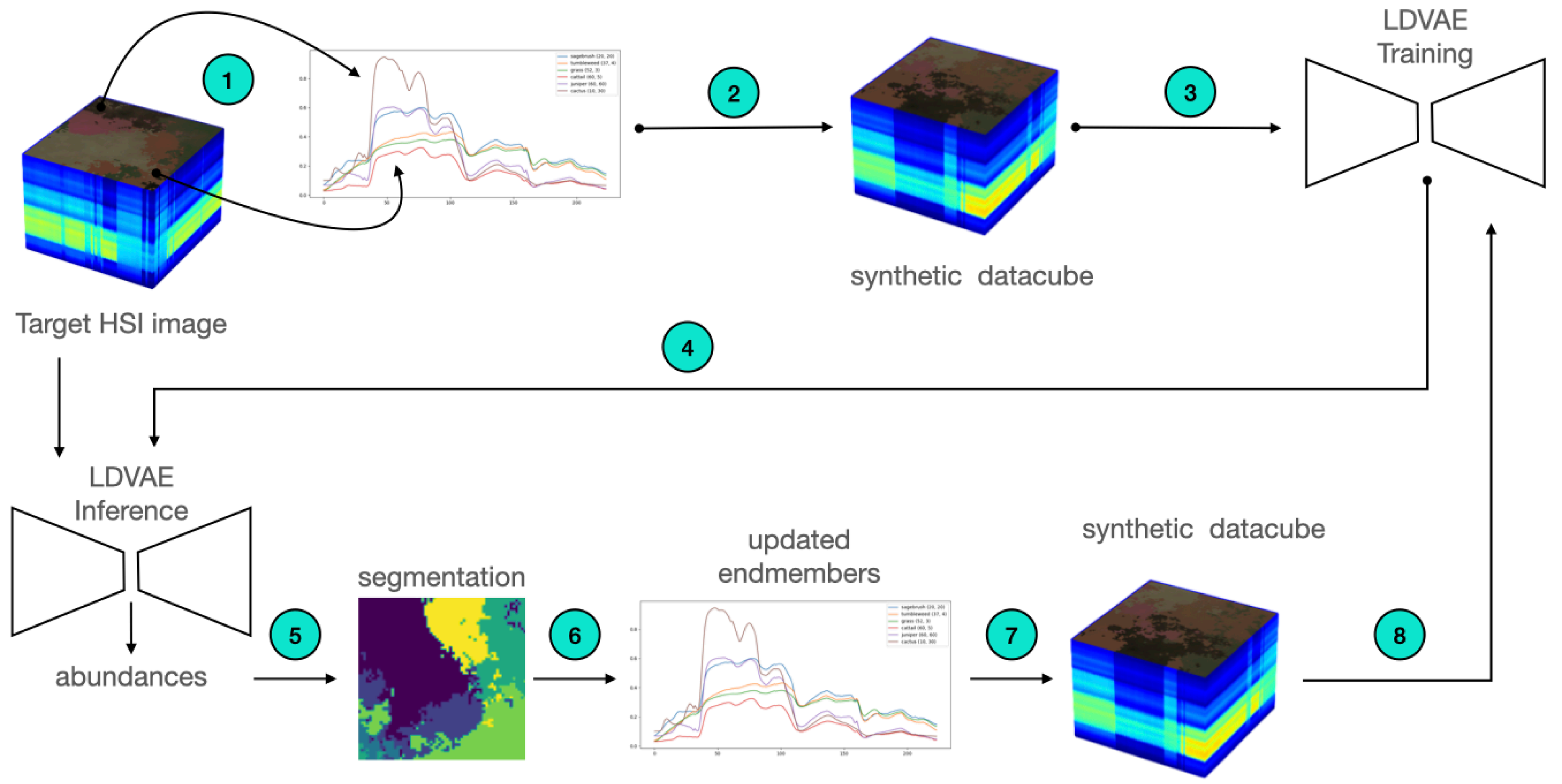
What is iLDVAE?

A method for Hyperspectral pixel unmixing that uses a Latent Variational Autoencoder (LDVAE) [1] within an analysis-synthesis loop to: (1) construct pure spectra of the materials present in an image; and (2) Infer the mixing ratios of these materials in hyperspectral pixels **without the need of labelled data.**



Loop Termination

iLDVAE loop is terminated when one of the two following conditions are met: 1) the number of allowed iterations is reached and 2) the disagreement err between endmembers estimations for two consecutive iterations is less than or equal to a pre-defined threshold ϵ, where

$$\mathrm{err} = \frac{1}{\rho N}\sum_{i=1}^{N}\sqrt{\frac{\|\mathbf{e}_i^{(k+1)} - \mathbf{e}_i^{(k)}\|^2}{L_i}}.$$

We define L_i and ρ as follows. Let $\mathbf{S}$ denote the segmentation image such that $\mathbf{S}_{(x,y)} = \mathrm{argmax}_i\, \mathbf{a}_{(x,y)}$. $\mathbf{S}$ is a single-channel image with the same spatial dimensions as $\mathbf{I}$. Each pixel in $\mathbf{S}$ contains the index of the most abundant endmember at that pixel. Then $L_i = \sum_{(x,y)} \mathbb{1}_{\mathbf{S}(x,y)=i}$, where $\mathbb{1}$ is the indicator function. Let

$$p_i = \max_{\forall \mathbf{S}_{(x,y)}=i} \mathbf{a}_{(x,y)}$$

denotes the maximum abundance value for endmember i then $\rho = \min\{p_i\}_{i=1}^{N}$.

Algorithm

Require: Target image $\mathbf{I}$
Require: The number of endmembers N present in the target image
Ensure: Estimated endmembers $\{\mathbf{e}_i\}_{i=1}^{N}$
Ensure: Estimated per-pixel abundances $\{a_i\}_{i=1}^{N}$ where $a_i \geq 0$ and $\sum_i a_i = 1$

1: $k = 0$ ▷ iteration count
2: Randomly select N pixels from $\mathbf{I}$ ▷ initial endmembers
3: Use $\{\mathbf{e}_i^{(k)}\}_{i=1}^{N}$ to synthesize $\mathbf{I}^{(k)}$ hyperspectral image where each pixel has random, but known, abundances
4: Train LDVAE on $\mathbf{k}^{(t)}$
5: Increment k
6: Use the LDVAE trained in the Step to estimate endmembers $\{\mathbf{e}_i^{(k)}\}_{i=1}^{N}$ and per-pixel abundances in $\mathbf{I}$
7: **if** err $\leq \epsilon$ **then**
8: Terminate loop
9: **end if**
10: Collect pixels for which $a_i >$ pure-pixel-threshold ▷ a_i denotes the abundance value for endmember i
11: Randomly select N pixels from the set of pixels in the previous step
12: **if** Maximum numbers of iterations reached **then**
13: Terminate loop
14: **end if**
15: Go to Step 3

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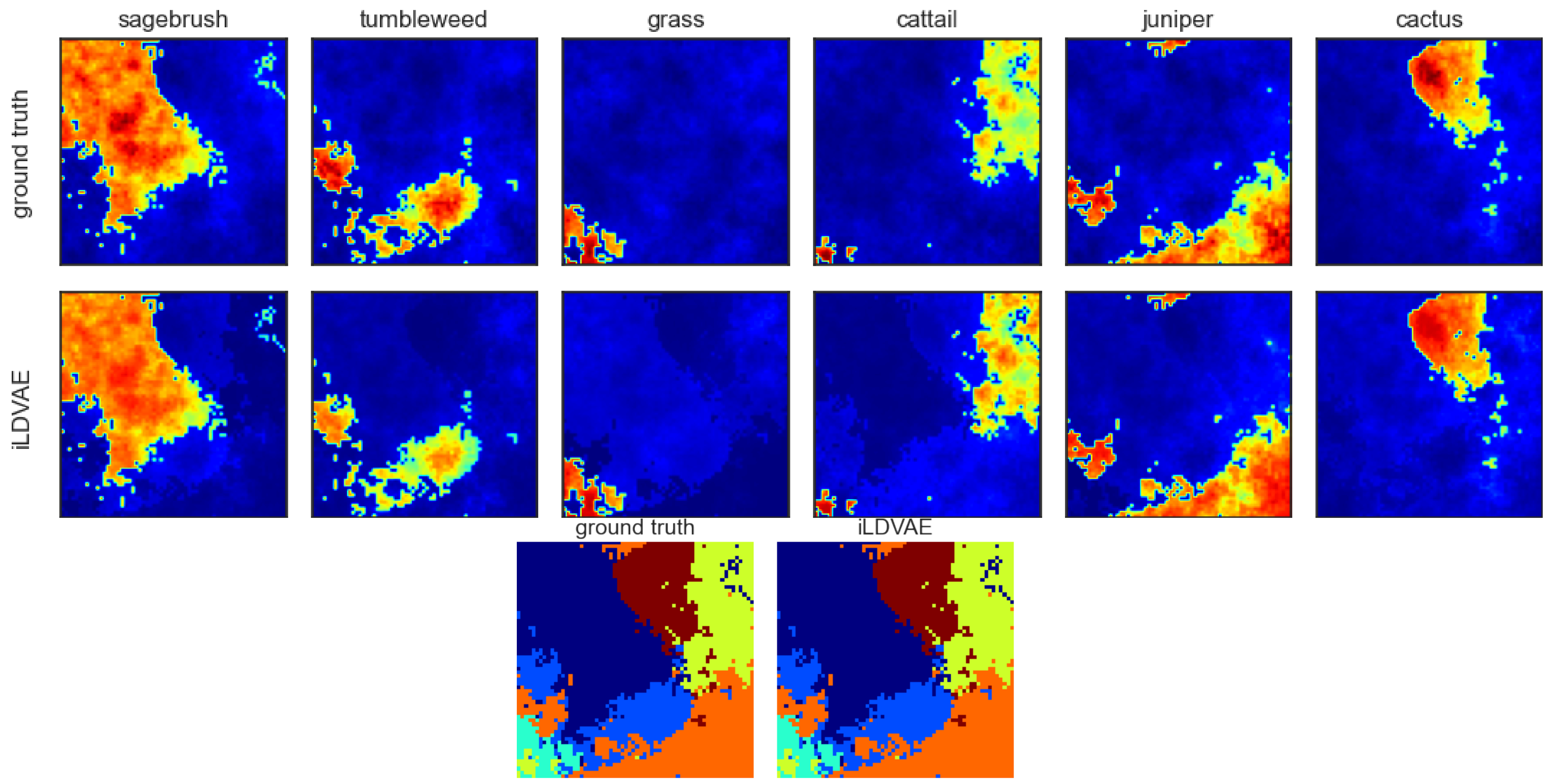
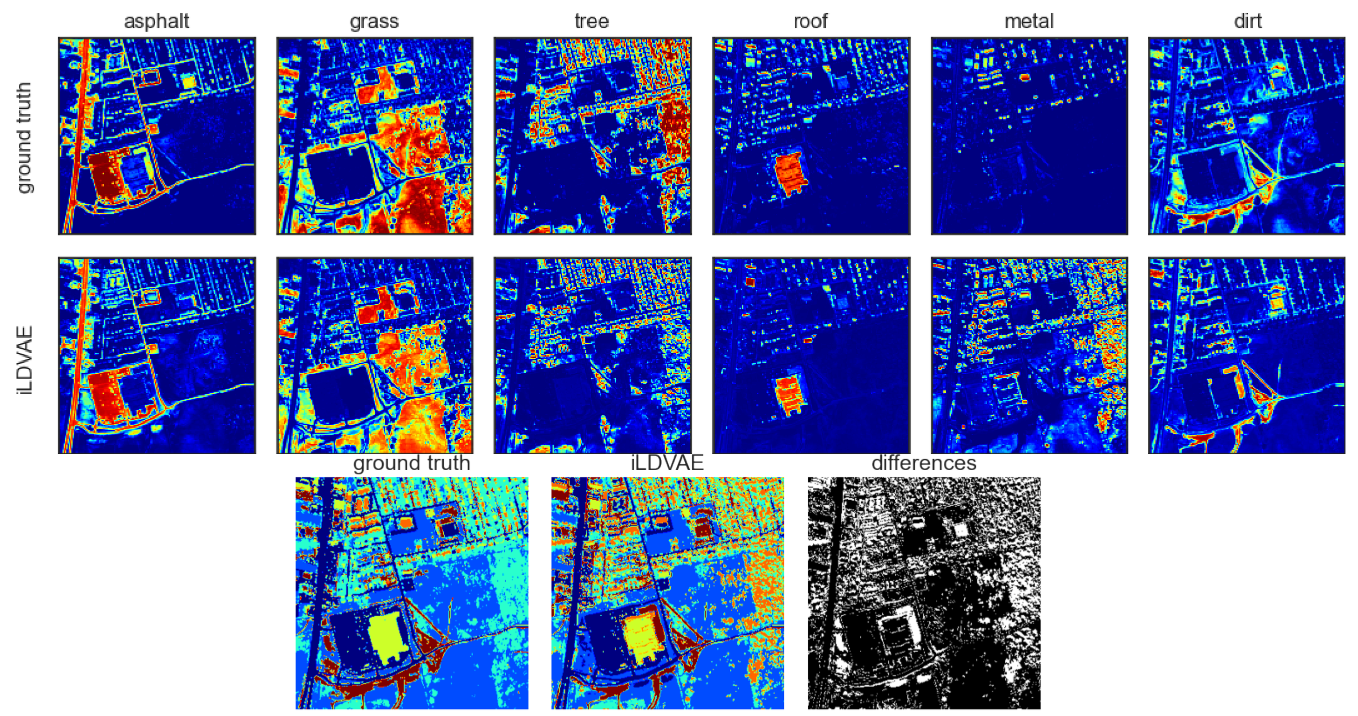
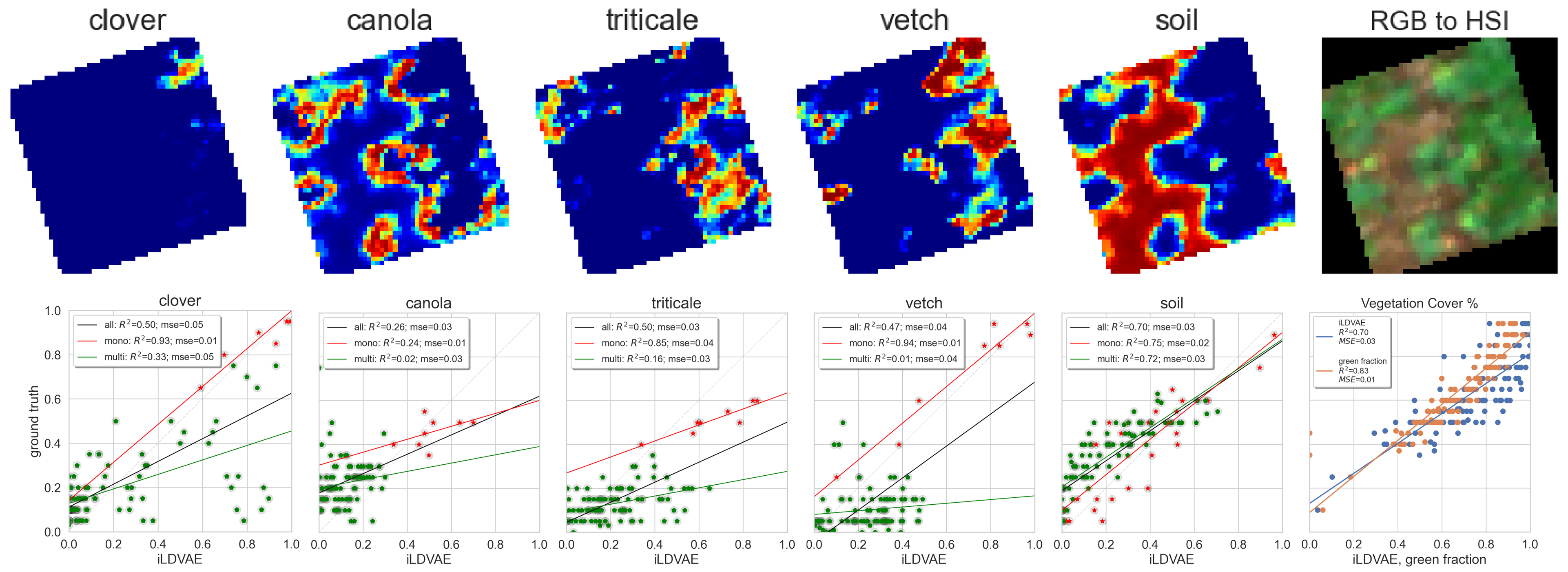


HYDICE Urban



Cover Crop USDA



Conclusions

- iLDVAE is capable of extracting endmembers estimating abundances per-pixel, **without** the need of ground truth "training" data.
- The proposed method is able to estimate proportions of various species plus soil in a given area by leveraging hyperpixel unmixing.
- Limitation: the proposed method requires pixels with high-purity index.
- Future work: include spatial-temporal features with Deep Convolutional Neural Networks and Data fusion, in addition to the existing hyperspectral spectral signal.

References

[1] Kiran Mantripragada and Faisal Z Qureshi. Hyperspectral pixel unmixing with latent dirichlet variational autoencoder. *arXiv preprint arXiv:2203.01327*, 2022.