**Blind cloud and cloud shadow removal of multitemporal images based on**

**total variation regularized low-rank sparsity decomposition**

Methodology

**Main achieves**

No need for cloud/shadow detection preprocessing

Integrate detection & removal of CS

High accuracy of CS detection & Info reconstruction

**Workflow**

1. **Regularization model: add info in order**

(1). Low-rank sparse decomposition (LRSD)

a. Low-rank prior of image component X

b. sparse prior pf the CS component S

(2). Spatial-spectral TV regularized LRSD

Heavy CS (ignored by sparse prior)

Preserve the spatial piece-wise smoothness & spectral continuity

Add spatial-spectral TV regularization to CS component

1. **ADMM algo: separate image and CS components**

Transform complex multi-var prob into several easy sub-probs:

(1). Fix Image component:

employ the Low-rank prior to extract X

(2). Fix CS component:

Employ sparse & spatial-spectral TV regularized priors to extract CS

**Function:**

Step-by-step separate X & S from the Obs

Integrate CS detection & removal

Optimize TVLRSD model:

(Optimize one var while fixing others in Iterative manner)

1. **CS detection & Info compensation**

Commission errors

(During the process of TVLRSD separation)

(1). CS detection

Threshold procedures

(ensuring the CS locs are right)

(2). Info compensation

For CS-free component

Replace X with original Y in CS-free areas

Experiments

Compared methods:

Completion-based methods \* 4

(matrix/tensor completion methods)

1. **Simulated experiments**

(quantitative analysis of the performance of CS removal & info reconstruction)

**Ground truth dataset:**

2 multitemporal RS images:

S2 & L8

**Experiment setting:**

Simulate CS, added into clean multitemporal RS images

Factors: Feature value & CS dist.

Indices: PSNR & SSIM

1. **Sentinel-2 dataset**

Simulate CS dist. randomly for each temporal image

Case 1: constant value to the cloud areas

Case 2: Real cloud data mask

Case 3: constant value for shadow based on case 1

Case 4: Rea cloud / shadow based on case 2

Adopt diff methods to get the CS values

1. **Landsat-8**

Influence of CS dist.

Add thin clouds in same locs and shapes in all temporal images

Case 5: constant value

Case 6: real cloud

TVLRSD with reference mask (TVLRSDR): upper bound of our compensation method

1. **Real experiments**

No need for CS detection as preprocessing

3 real contaminated multitemporal RS datasets

Sentinel-2, Sentinal-2, SPOT-5

3 algos CS detection beforehand:

(for compared completion-based methods)

F-mask algorithm (S2(1))

Sen2Cor tool (S2(2))

MAJA processor (SPOT-5)

**Results:**

Better results in CS removal & Info reconstruction

Better CS detection results compared to other cloud mask

(by exploiting surface info under thin clouds and cloud shadows in multitemporal images)

(by iteratively separating the surface info and CS)

Proposed method can separate the low-rank clean image and sparse CS components

Last CS detection and information compensation help the model be more accurate

Detected CS locations with higher accuracy can further improve the image quality.

Blind CS removal method achieves the best results compared with the other methods

Discussion

TVLRSDC superior to other state-of-the-art completion-based methods

**Other:**

only consider image low-rank prior

Regard CS as missing info

**TVLRSDC:**

* consider CS prior
* Make full use of degraded surface info in thin C and CS areas of multitemporal images
* Image decomposition framework realize cloud removal & Info reconstruction under thin CS
* Low-rank regularization used to reconstruct info in CS areas
* Sparse and TV regularizations used to extract CS component
* Image and CS components can be separated iteratively
* Thresholding strategy to detect CS (location)
* The CS detection in the end help the info compensation of CS-free areas
* CS detection & Infor compensation preserve the CS-free info
* Accurate and stable results in info recovery & CS detection for various datasets

**Limitations:**

* Not suit for large sample dataset

(too much computation and storage)

* Not suit for thick cloud all the time

(might be considered as low-rank image component)

* Hard to find perfect params to avoid commission errors

Conclusion

* Remove and detect CS in multitemporal RS images via

Low-rank Sparsity Decomposition framework

* Image component and the CS component are estimated (separated) iteratively
* Low-rank prior models the spectral-temporal correlations of multitemporal images: separate clean image and CS
* Sparse and spatial-spectral TV regularization on CS component:

isolate CS from image

* Thresholding method – detect CS area

Image restoration only in CS areas

Info compensation only in CS-free

**Future:**

* Incorporate physics-based priors into image decomposition framework
* Consider tensor-based optimization models