Unbiased Histogram Matching Quality Measure For Optimal Radiometric Normalization

Zhengwei Yang, Rick Mueller
USDA/NASS/ R&D Division

OUTLINE

- Why Histogram Matching for Radiometric Normalization
- Histogram Matching Method
- Histogram Matching Optimization for Radiometric Normalization
- Performance Metric - Similarity Measurement
- Experiments & Results
- Conclusions

Why Histogram Matching for Radiometric Normalization

- Radiometric correction is critical to change detection and other applications
- Why histogram matching normalization?
  - It's a relative radiometric normalization method;
    - Less expensive, always feasible,
    - applicable across sensors.
    - No sensor information required;
  - No need to subjectively select pseudo invariant areas for parameter estimation
  - Most imageries involves only small portions of changes
  - The nonlinear transformation fits better for nonlinearity

Histogram Matching Method

Let $p_u(x_i)$ and $p_v(y_i)$ be histograms of grey level $u=x_i$ and $v=y_i$. Their distributions are:

$$w_u(n) = \sum_{i=0}^{n} \mathrm{p_u}(\mathrm{x_i}) \;, \qquad w_v(k) = \sum_{i=0}^{k} \mathrm{p_v}(\mathrm{y_i}) \;, \qquad n, k = \{0, \ldots, L-1\}$$

Then, the histogram matching of the given $u=x_i$, is given by $v=y_k$, *where k is the* minimum value which satisfies $w_u(n) <= w_v(k)$.

Histogram Matching Optimization for Radiometric Normalization

- Why histogram matching optimization?
  - Different reference image yields different residual error;
  - For change detection, either images can be selected reference;
  - Which one is of better performance?
- How to determine which one is better?
  - Define a similarity measure:

$$s_{rk}(x,y,k) = f(I_r(x,y,k), I_{rh}(x,y,k))$$

  - Find reference image with best similarity for histogram matching:

$$\underset{r,k}{MAX}\{s_{rk}(x,y,k)\},\ \forall k \in \{1,2,...,K\},\quad r\ \{1,2,...,L\}$$

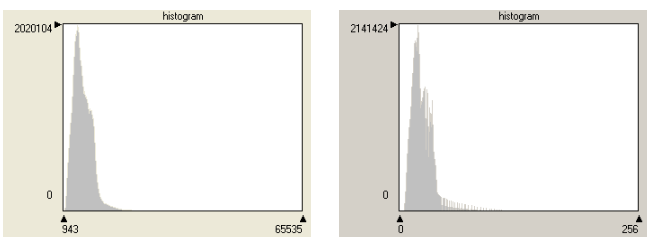
  - Specifically, which similarity measure is proper?

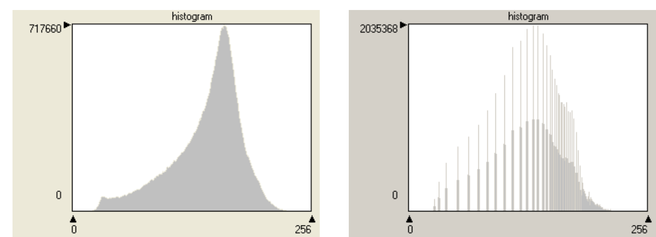
Performance Metric - Similarity Measures

- There are many similarity measures existing;
  - Euclidean distance used of normalization performance comparison;
  - Manhattan distance used for performance measurement of histogram matching;
  - Both are isotropic and biased for variables with different scale.

Example:

A





B

- A scale invariant measure needed!

Image Ratioing

- The scale invariant similarity measure - Image ratio:

$$r(i,j,k) = \frac{I_r(i,j,k)}{I_{rh}(i,j,k)}, \qquad \textit{for } k\ \{1,2,\ \ldots,\ K\}$$

- It is simple, but don't reflects absolute radiance change;
- It is asymmetry metric
  - The ratio differs dramatically when switching the numerator and denominator;
  - Hard to perform thresholding;
- It is not summable. e.g. $(r_1+r_2)/2 = (0.8+1.2)/2=1$ => No Change
- It's not suitable for images from different spectral bands

Symmetric Image Ratio (SIR)

- To overcome these shortcomings, a new symmetric image ratio is proposed as following:

$$r_{rk}(i,j) = \begin{cases} \dfrac{I_r(i,j,k)}{I_{rh}(i,j,k)}, \forall I_r(i,j,k) \le I_{rh}(i,j,k) \\ \dfrac{I_{rh}(i,j,k)}{I_r(i,j,k)}, \forall I_r(i,j,k) > I_{rh}(i,j,k) \\ 0, \forall (I_r(i,j,k) = 0 \vee I_{rh}(i,j,k) = 0) \end{cases}$$

- Summable - Overall similarity of two images is given by:

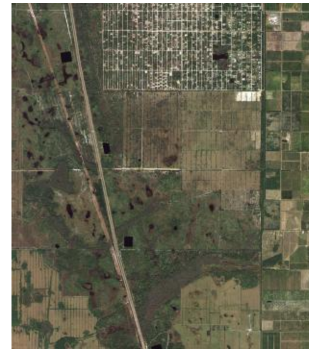
$$s_{rk} = \sum_{i=1}^{M} \sum_{j=1}^{N} r_{rk}(i,j), \;\; k\,\{1,2,\ldots,K\}, \;\; r\,\{1,2,\ldots,L\}$$

Experiments & Results

Original & Histogram Matched Images

Original images (a) unclipped 2004 8-bit image; (b) Clipped 2004 8-bit image; (c) 1999 8-bit image;

(a)



(b)

(c)

(d)

(e)

(f)

(g)

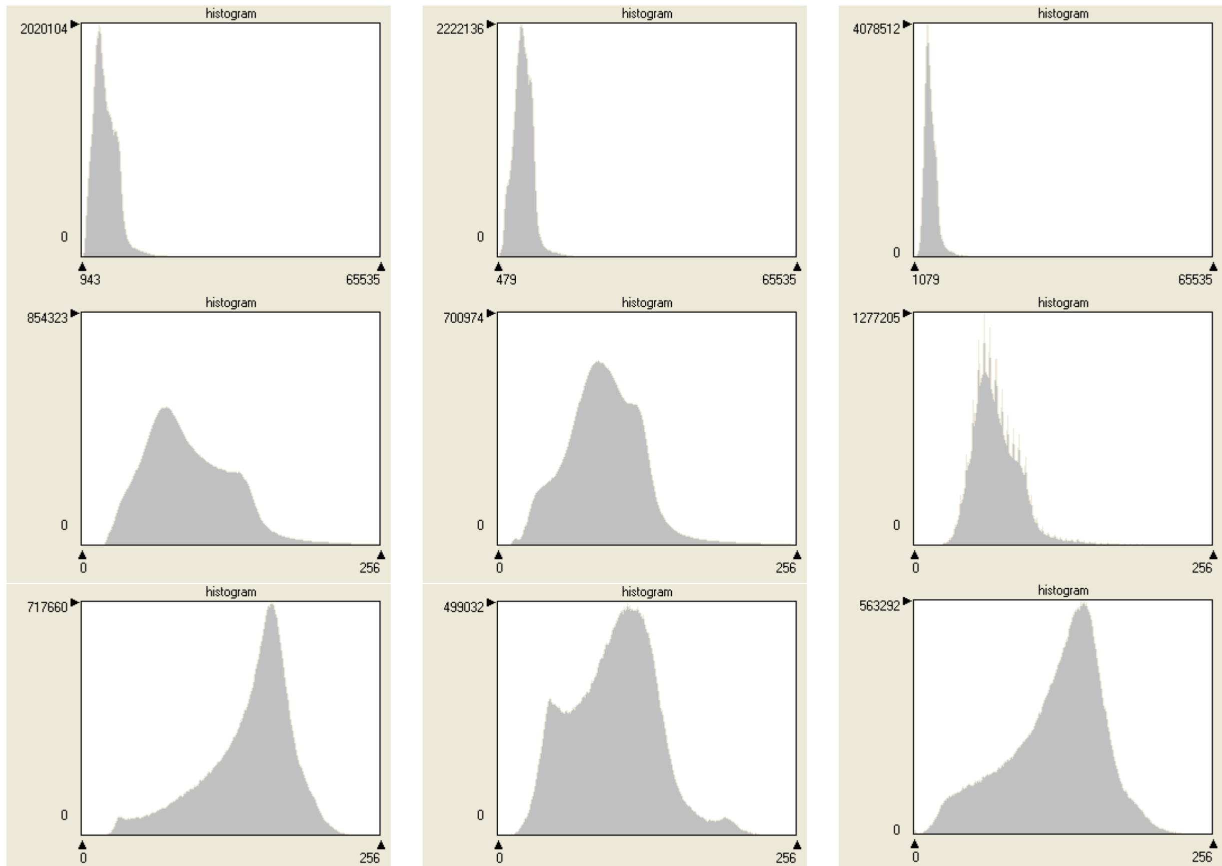
Histogram matched images: (d)1999 image with clipped 2004 reference; (e) Original 2004 image with 1999 reference; (f)1999 image with unclipped 2004 reference; (g) Unclipped 2004 with 1999 reference

Reference Image Histograms

Unclipped 2004 8-bit image histograms

Clipped 2004 8-bit image histograms

Original 1999 8-bit image histograms



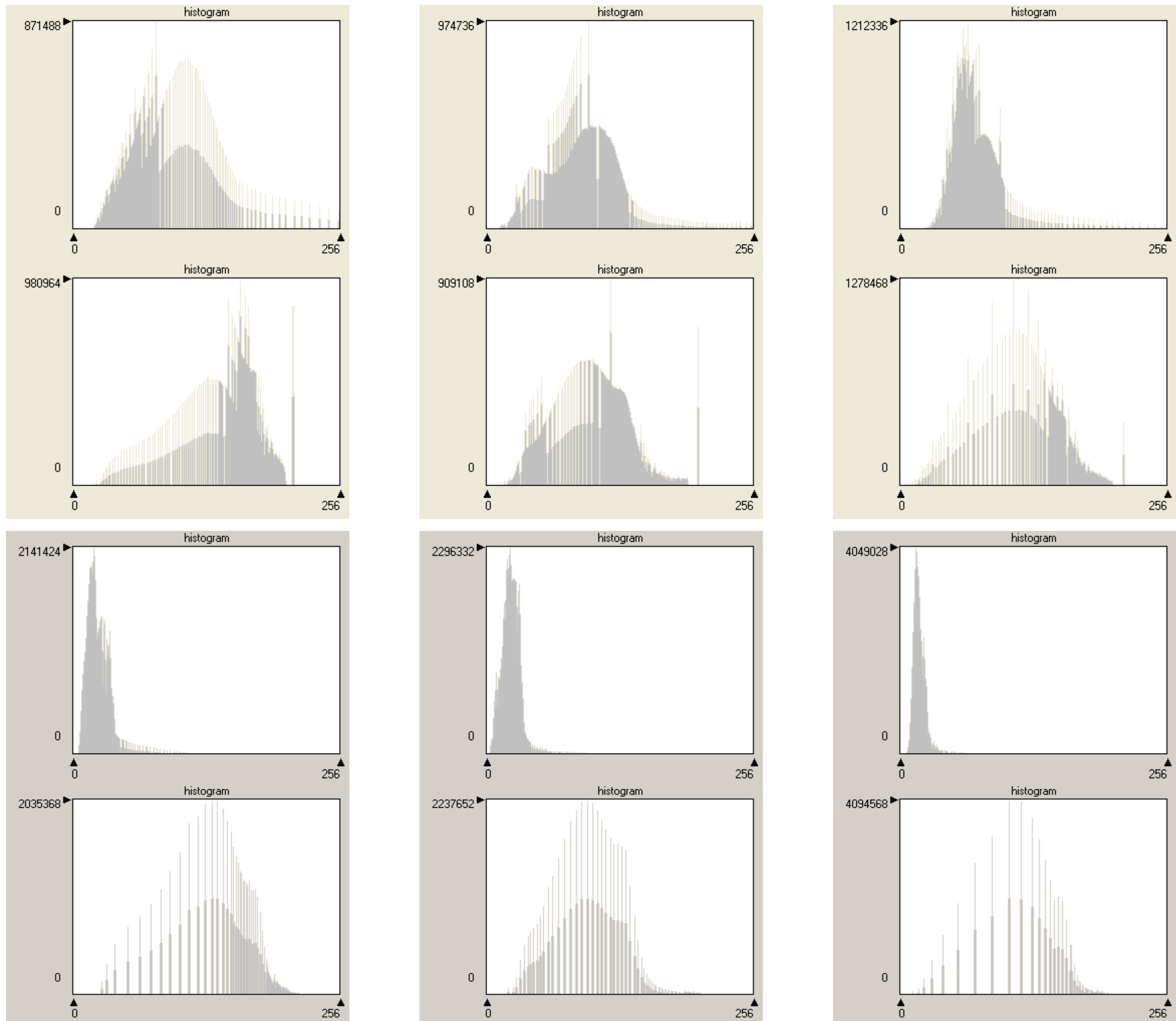
Histogram Matched Image Histograms

Histogram matched original 1999 image histograms with clipped 2004 image as reference

Histogram matched 2004 clipped image histograms with 1999 image as reference

Histogram matched 1999 image histograms with unclipped 2004 image as reference

Histogram matched unclipped 2004 image histograms with original 1999 image as reference



Manhattan Distance Measure Results

- The Manhattan distance measurement of image similarity of the non-normalized images and the histogram matching normalized images with different reference images and different bands.

Table 1. Manhattan distance measuring results for images without image clipping.

Unclipped 2004 image	Band 1	Band 2	Band 3
No Normalization	5,165,526,637	*3,334,340,163*	4,489,143,486
HMN, 1999 Image as Reference	1,333,636,088	*1,164,335,668*	1,238,088,703
HMN, 2004 Image as Reference	**440,286,597**	**318,965,703**	***223,107,908***

Table. 2. Manhattan distance measuring results for images with image clipping.

High-bit clipped 2004 image	Band 1	Band 2	Band 3
No Normalization	2,460,670,698	*1,242,35,0692*	2,344,830,977
HMN, 1999 Image as Reference	**1,353,792,013**	*1,180,279,785*	1,255,995,069
HMN, 2004 Image as Reference	1,584,393,561	**1,159,968,546**	***825,605,177***

Symmetric Image Ratio Measure Results

Table 3. Symmetric image ratio measuring results for images without image clipping.

Unclipped 2004 image	Band 1	Band 2	Band 3
No Normalization	7,804,863	*11,139,156*	7,493,628
HMN, 1999 Image as Reference	**35,314,399**	**33,674,501**	34,378,529
HMN, 2004 Image as Reference	30,706,733	33,069,553	***35,408,049***

Table 4. Symmetric image ratio measuring results for images with image clipping.

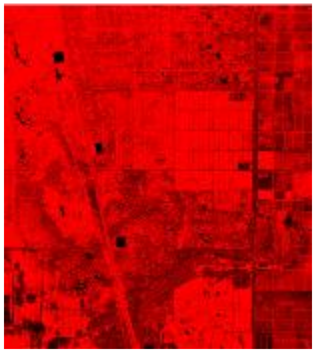
High-bit clipped 2004 image	Band 1	Band 2	Band 3
No Normalization	27,544,433	*33,053,400*	25,968,637
HMN, 1999 Image as Reference	***35,325,968***	**33,686,762**	34,374,198
HMN, 2004 Image as Reference	31,100,131	33,389,944	***35,622,059***

Observations

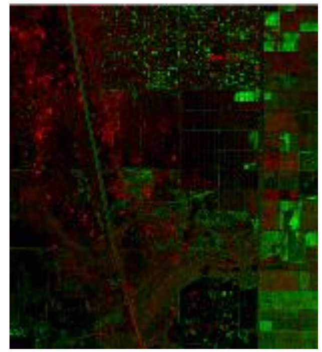
- From Table 1 & 2 (for Manhattan), the reference and bands with minimum differences are unchanged;
- After clipping (compact histogram spread), the difference significantly changed;
- The ordinal rank of the similarity changes after clipping;
- From Table 3&4 (for SIR),the reference and bands with minimum differences are unchanged;
- After clipping, the difference significantly changed if no HM, but no change after HM;
- The ordinal rank of the similarity unchanged;
- SIR results for corresponding reference & band remain roughly same regardless if the image clipped or not; This means not bias!
- However, the ordinal rank of the similarity from SIR differs from that from Manhattan distance measure; Especially, Band 1 using 1999 ref, it has highest similarity in SIR, but not in Manhattan.

Change Maps from Manhattan Distance with Different Reference Images

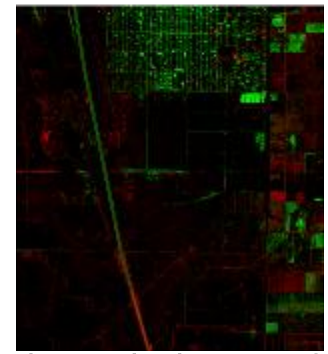
Unclipped



a1) Band2 (Direct difference)



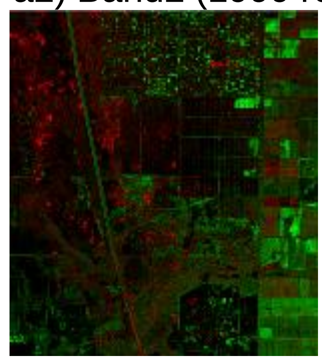
a2) Band2 (1999 reference)



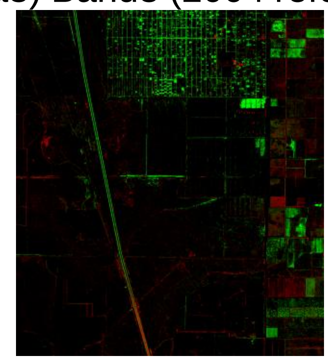
a3) Band3 (2004 reference)

Clipped

b1) Band2 (Direct difference)



b2) 1999 reference)

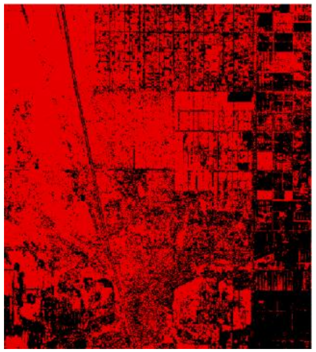


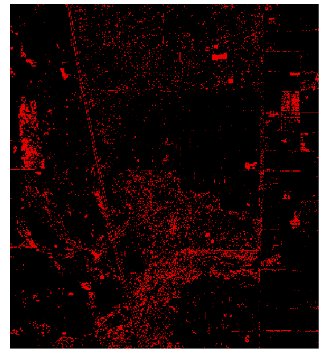
b3) 2004 reference

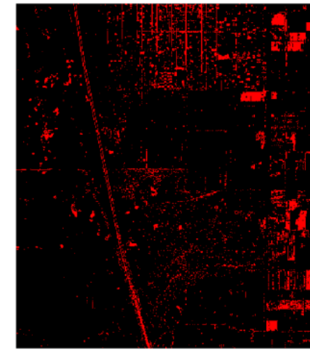
(a) Changes detected with unclipped 2004 image;
(b) Changes detected with clipped 2004 image.

Change Maps from Symmetric image Ratio with Different Reference Images

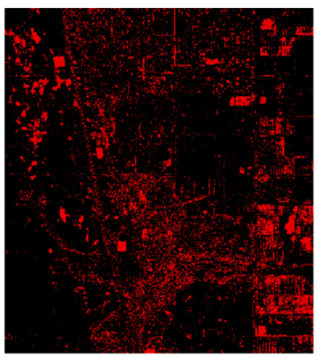
Unclipped

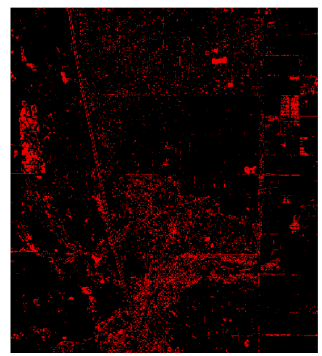

c1) Band2 (Direct SIR)

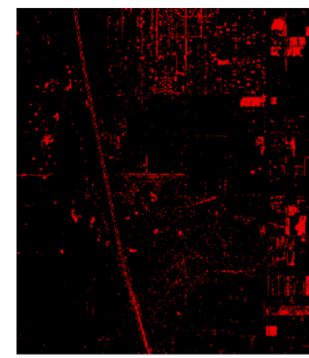

c2) Band1 (1999 reference)


c3) Band3 (2004 reference)

Clipped


d1) Band2 (Direct SIR)


d2) Band1 (1999 reference)


d3) Band3 (2004 reference)

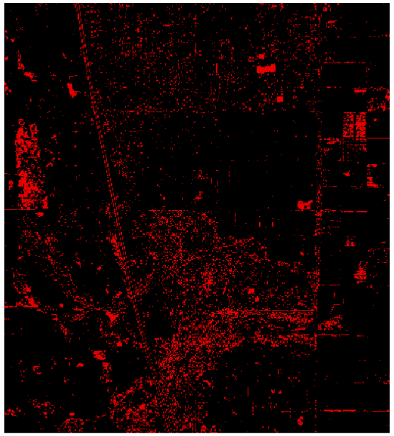
(c) Changes detected with unclipped 2004 image;
(d) Changes detected with clipped 2004.

Conclusions

- The new symmetric image ratio is scale invariant and unbiased to the low bit concentrated image histogram
  - SIR results show that the clipping does not affect result;
- It is symmetric and is consistently ranging in [0, 1]
  - 0 represents least similarity
  - 1 represents the maximum similarity;
- It is better than regular Image ratioing for change detection
  - Consistent measure, normalized values, and easy thresholding;
- Quality control needed for picking band for data from multi-sensors
  - Make sure the interested objects not suppressed.
- But it inherits some regular image ratioing drawbacks:
  - Does not reflect physical radiometric
  - Enhances some land cover spectral features while suppressing others;

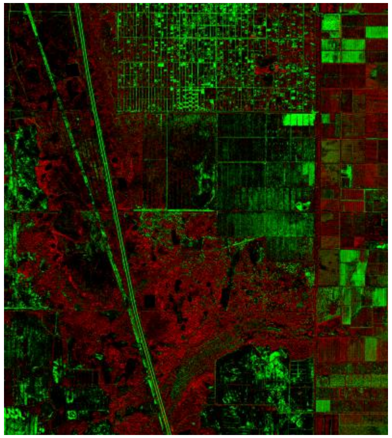
Comparison of Manhattan Distance and Symmetric Image Ratio for Band 1

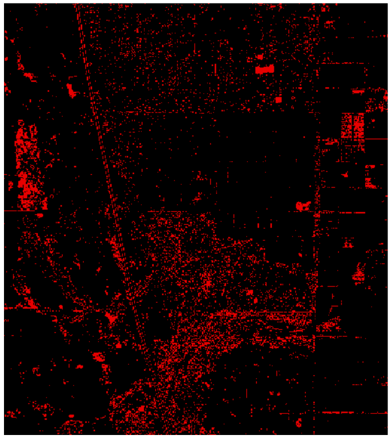
Manhattan



SIR

Change map with 1999 image as reference





*Reference and subject bands of different spectral coverage

Change map with 2004 image as reference

THANK YOU!

QUESTIONS?

Tel: 703-877-8000x145
Email: zhengwei_yang@nass.usda.gov

USDA

NASS
FACT FINDERS FOR AGRICULTURE
UNITED STATES DEPARTMENT OF AGRICULTURE