Multi-Camera Color Correction via Hybrid Histogram Matching

https://njuvision.github.io/HHM/

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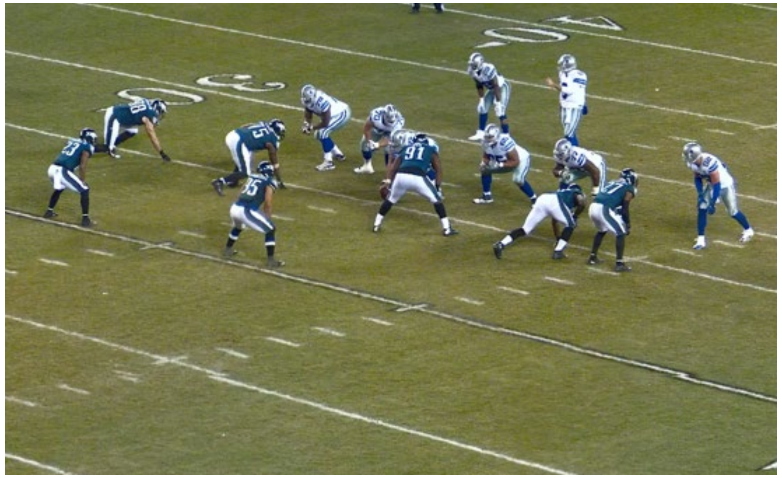
1. Introduction

- Multi-camera system

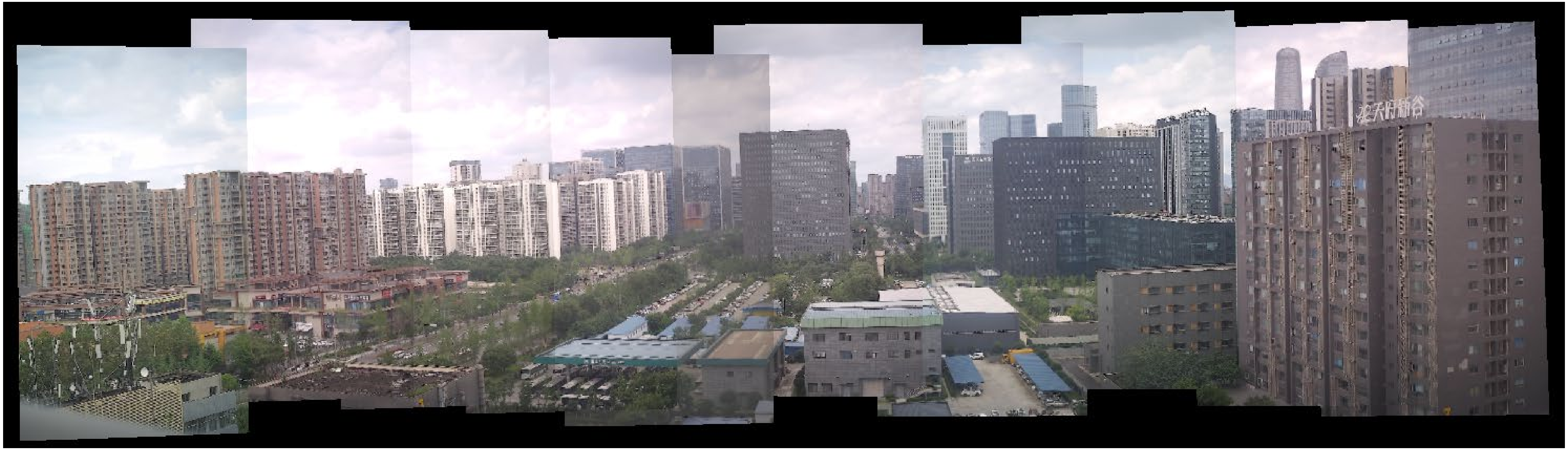


- Application scenarios



1. Introduction

☐ Multi-camera color difference

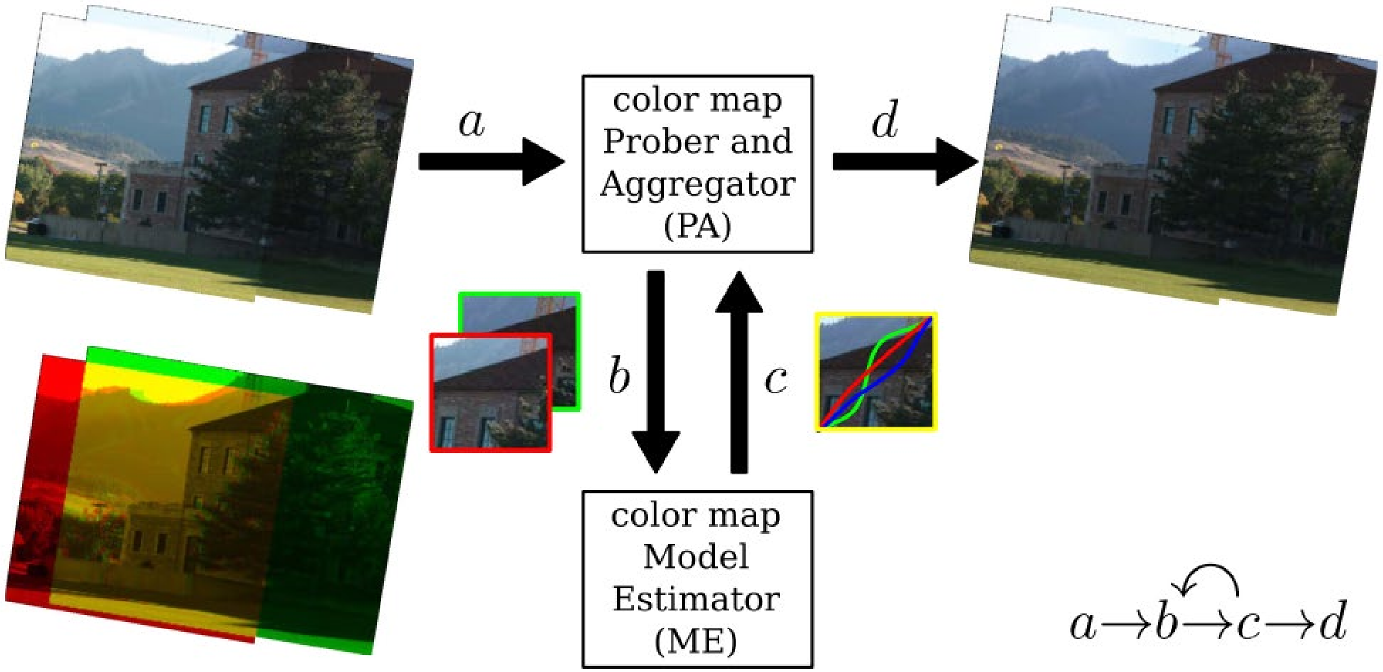


Sources of the difference: different camera system & different parameters

2. Related work

Processes of color correction

- Color correction can be divided into two steps: **ME** and **PA**.



PA is using mapping function on target image.

ME is using color difference image pairs to estimate Mapping function.

$a \rightarrow b \rightarrow c \rightarrow d$

2. Related work

- State-of-the-art Color Correction Algorithms

Algorithm	Color Space	Description
R [8]	$l\alpha\beta$	Use the mean and variance of two images for color mapping matrix
AM [12]	RGB	Apply least squared minimization on input two images for color mapping matrix
HM [17]	RGB	Utilize the cumulative histograms of overlapped areas from two images for color mapping function
G [19]	RGB	Approximate the color mapping function assuming the Gaussian distributed histogram of two images
3MS [6]	RGB	Derive 6-node spline model for color mapping using paired SIFT points from overlapped areas
GPS [15]	RGB	Generate 4-knot spline model with gradient preserving feature from overlapped areas for color mapping
Proposed HHM	RGB	1) Use cumulative histograms from overlapped areas for global mapping function; 2) Remove noisy mapping pair via re-ordered cumulative histogram; 3) Directly connect neighbor points if there are vacancies in between for local straightening

2. Related work

Performance Evaluation Metrics

$$M_g = \frac{1}{2}(M_s + M_t)$$

Metrics:

PSNR (Peak Signal-to-Noise Ratio)

SSIM (Structural Similarity)

FSIM (Feature Similarity Index)

iCID (improved Color Image Difference)

Source image vs *Corrected image*

Target image vs *Corrected image*

Taking PSNR as an example:

- M_s is the PSNR measured using the pixels from the overlapped area of source image and its color corrected sample.
- M_t is the corresponding PSNR for the overlapped area in target image and its corresponding color corrected representation.

3. Proposed method

- Histogram Matching in color correction (Fecker's method)

Some errors exist!

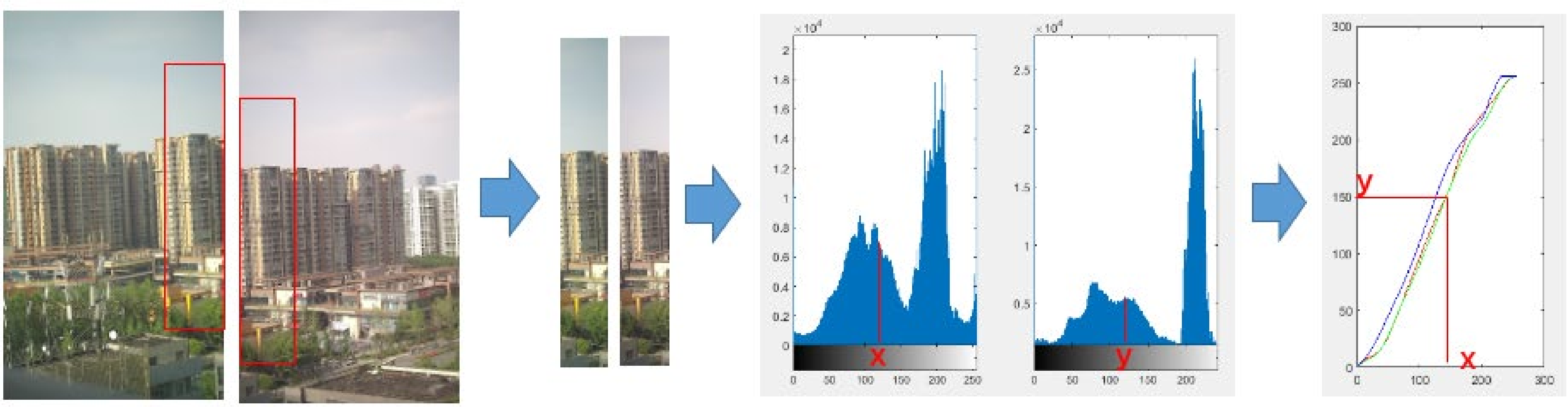


Image pair

Overlapped region

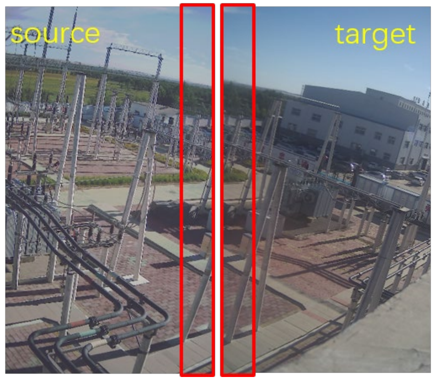
Distribution histogram

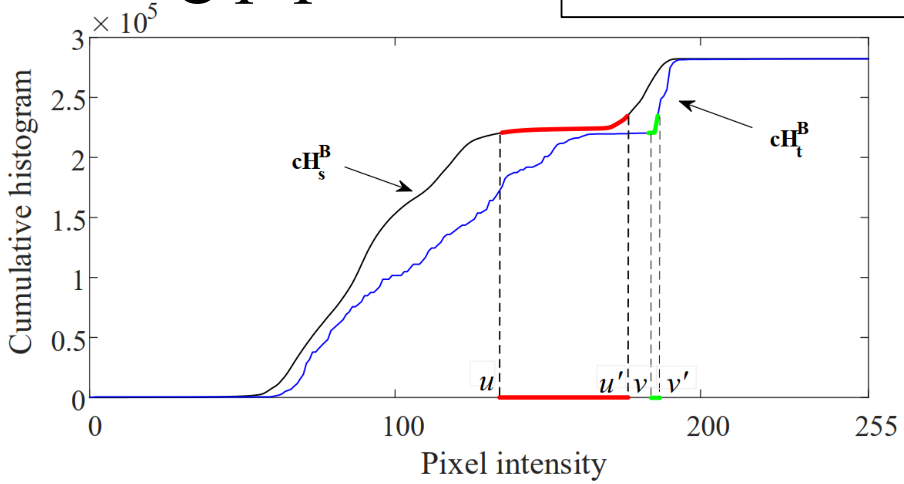
Accumulative histogram & color matching

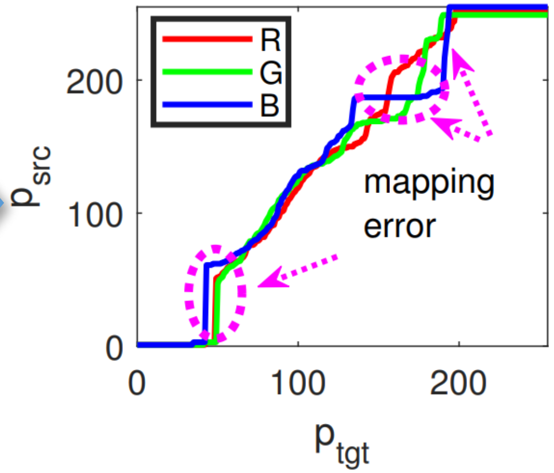
3. Proposed method

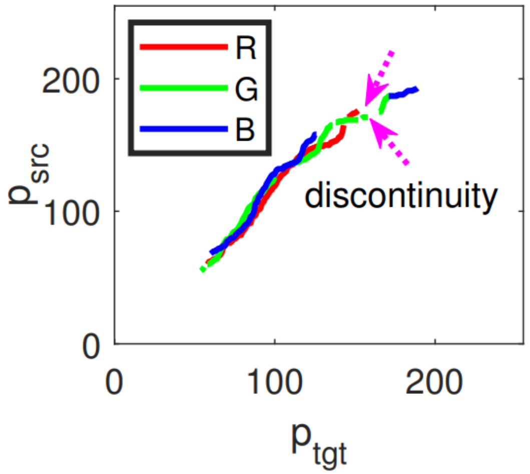
- Hybrid histogram matching pipeline

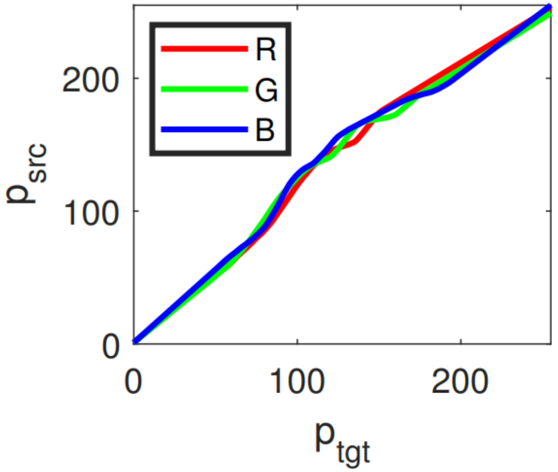
Our Method

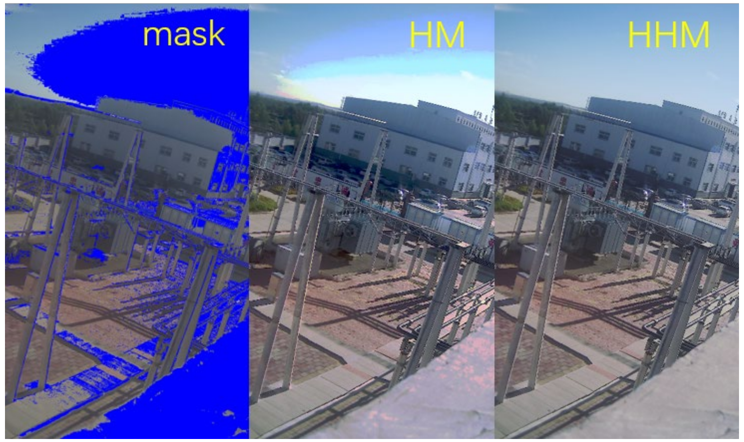






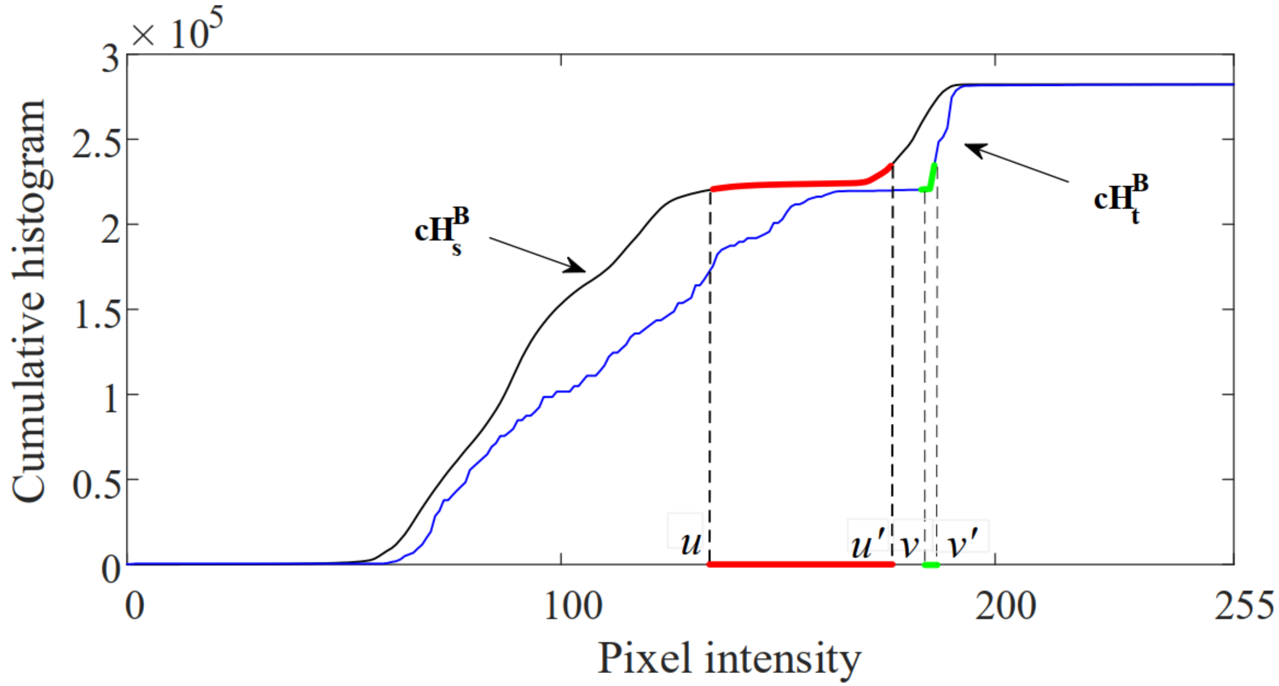


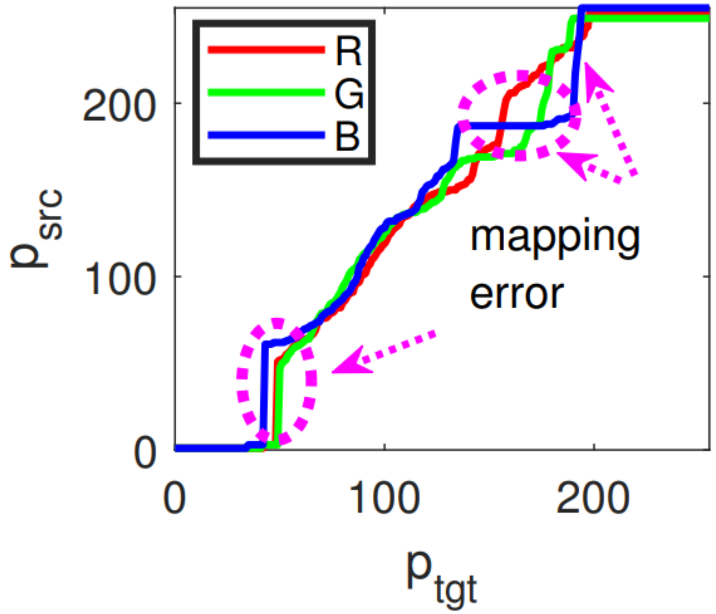




3. Proposed method

(1) Histogram Matching

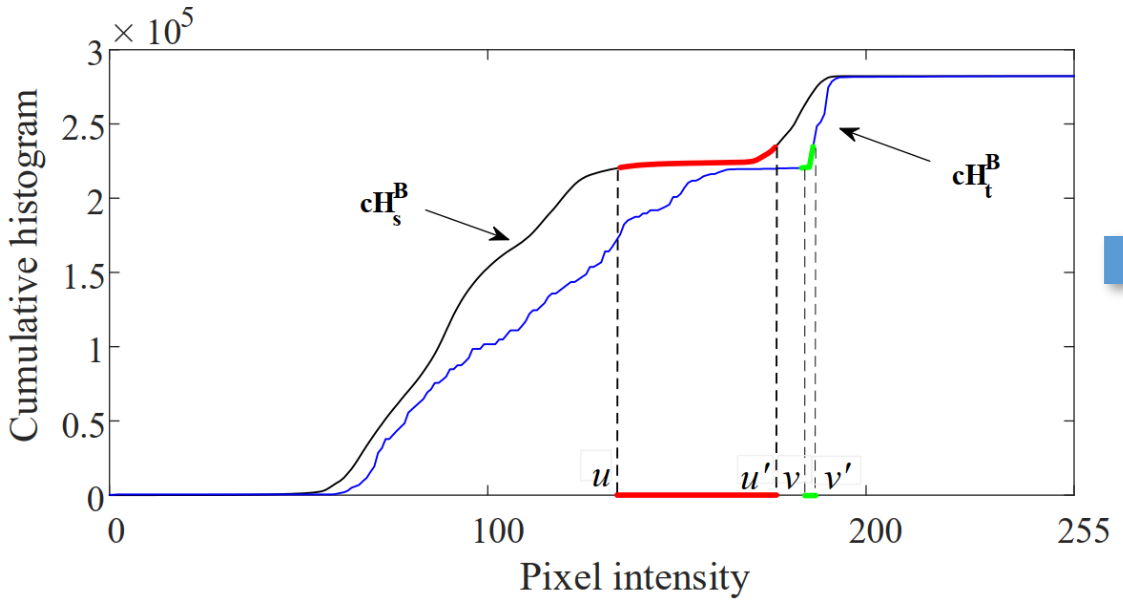


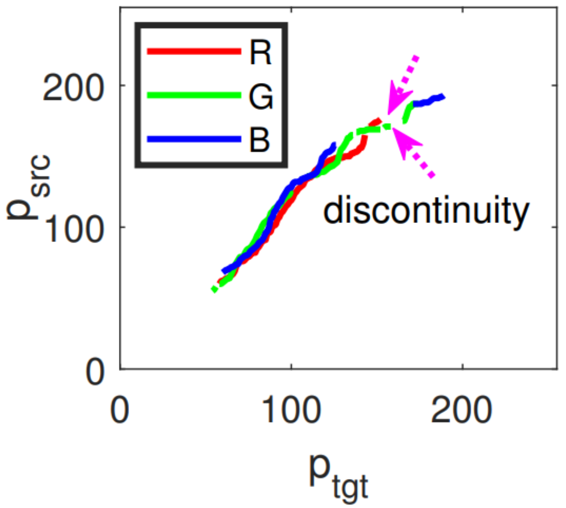


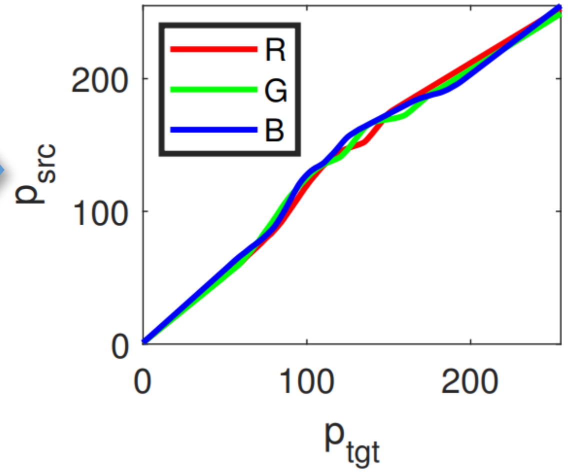
Some errors exist!

3. Proposed method

(2) Local-straightening & Smooth







These errors have been corrected.

3. Proposed method

☐ Algorithm

Pseudocode

Algorithm 1 Hybrid Histogram Matching-based Dual-Camera Color Correction HHM()

Input: $\mathbf{O}_t$, $\mathbf{O}_s$; //Overlapped region of respective target and source images. Note that following steps will be iterated consecutively for R, G, B channels.

Output: f^c_{map}, $c \in \{\text{R}, \text{G}, \text{B}\}$.

for $c \in \{\text{R}, \text{G}, \text{B}\}$
//global color mapping.
  $\mathbf{O}^c_t \rightarrow \mathbf{H}^c_t$; $\mathbf{O}^c_s \rightarrow \mathbf{H}^c_s$; //derive histogram
  $\mathbf{H}^c_t \rightarrow \mathbf{cH}^c_t$; $\mathbf{H}^c_s \rightarrow \mathbf{cH}^c_s$; //drive cumulative histogram
  for $0 \leq v \leq 255$ //8-bit pixel precision assumption
    while $u \leq 255$
      if $\mathbf{cH}^c_s(u) \leq \mathbf{cH}^c_t(v) < \mathbf{cH}^c_s(u+1)$
        $f^c_{\text{map}}(v) = u$;
        break;
      end if
      u++;
    end while
  end for
//local noisy mapping pair straightening.
  $\tilde{f}^c_{\text{map}} = \boxed{\text{LocalStraightening}(f^c_{\text{map}}, \mathbf{O}_t, \mathbf{O}_s);}$
//mapping function smoothing
  $\hat{f}^c_{\text{map}}$= WindowSmoothing($\tilde{f}^c_{\text{map}}$, n_w); //n_w:# of points in smoothing window.
end for

Algorithm 2 Local Noisy Mapping Pair Straightening LocalStraightening()

Input: f^c_{map}, $\mathbf{O}_s$, $\mathbf{O}_t$

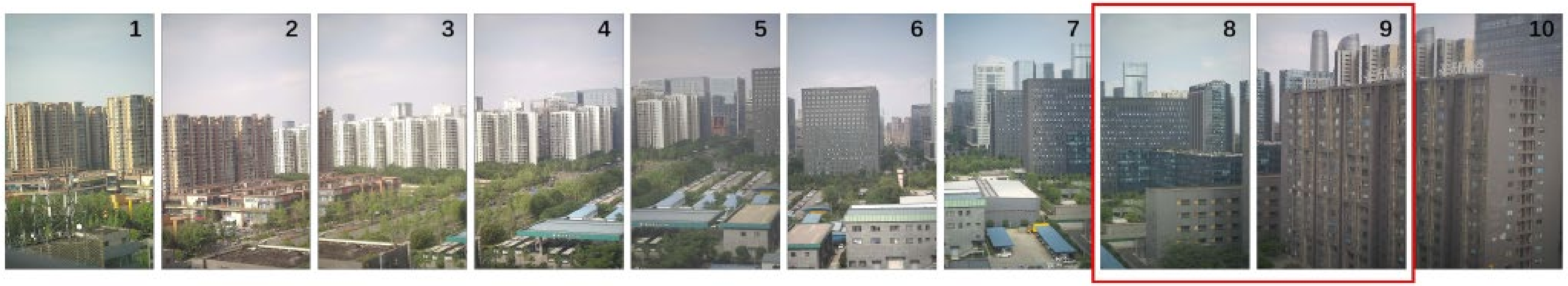
Output: $\tilde{f}^c_{\text{map}}$, $c \in \{\text{R}, \text{G}, \text{B}\}$. //local straightened color mapping function.

for $c \in \{\text{R}, \text{G}, \text{B}\}$
//noisy mapping pair derivation
  $\mathbf{O}^c_t \rightarrow \mathbf{H}^c_t$; $\mathbf{O}^c_s \rightarrow \mathbf{H}^c_s$; //derive histogram
  $\mathbf{H}^c_t \rightarrow m^c_t$; $\mathbf{H}^c_s \rightarrow m^c_s$; //derive the total number of pixels
  $\mathbf{H}^c_t \rightarrow \tilde{\mathbf{H}}^c_t$; $\mathbf{H}^c_s \rightarrow \tilde{\mathbf{H}}^c_s$;//re-order the pixel bins from the default $\{0, 1, \ldots, 255\}$ to $\{i_0, i_1, i_2, ..., i_{255}\}$ with their histogram from the least to the most one. $\tilde{H}^c[i_0] \leq \tilde{H}^c[i_1] \leq \cdots \leq \tilde{H}^c[i_{255}]$
  $\tilde{\mathbf{H}}^c_t \rightarrow \mathbf{c}\tilde{\mathbf{H}}^c_t$; $\tilde{\mathbf{H}}^c_s \rightarrow \mathbf{c}\tilde{\mathbf{H}}^c_s$; //derive cumulative histogram
  for $k = 0, 1, ..., 255$ //derive noisy pixel bins for removal.
    if $\mathbf{c}\tilde{\mathbf{H}}^c_t(k) < \eta \cdot m^c_t$ //η noisy level in percentile.
      $\vec{i}^{\,t} += i^t_k$;
    end if
    if $\mathbf{c}\tilde{\mathbf{H}}^c_s(k) < \eta \cdot m^c_s$
      $\vec{i}^{\,s} += i^s_k$;
    end if
  end for
  $f^c_{\text{map}} \rightarrow \tilde{f}^c_{\text{map}}$; //remove $\vec{i}^{\,s}$ and $\vec{i}^{\,t}$ associated pairs and connect neighbors with straight line if there are missing points in between.
end for

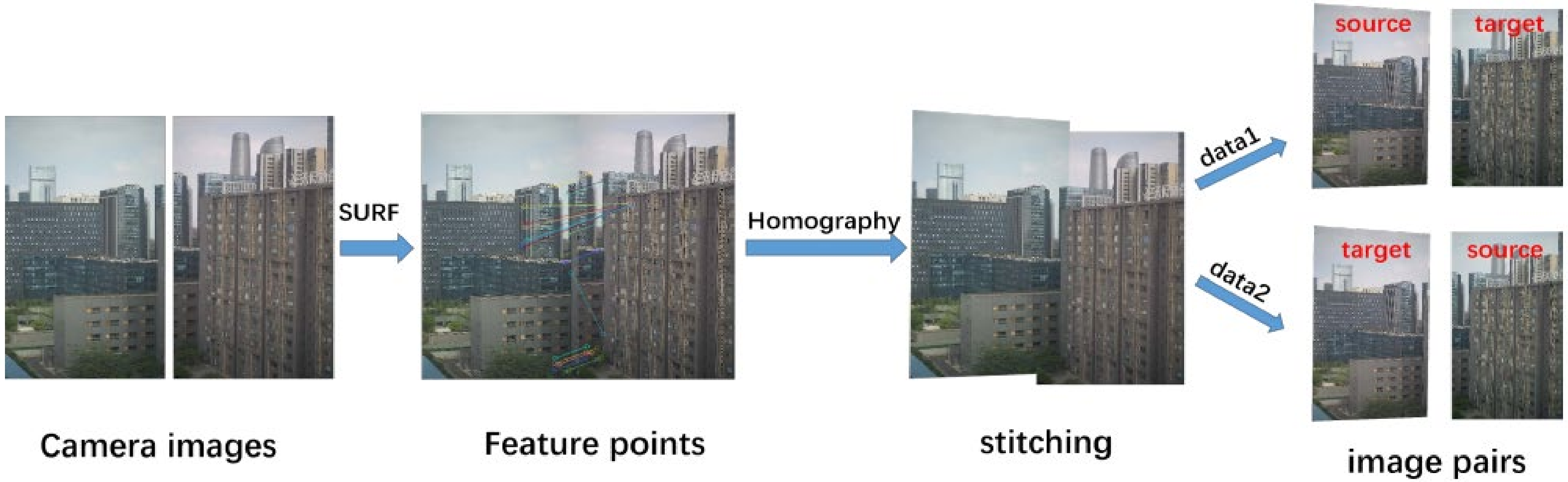
4. Experiment and Results

- Dataset

Camera image:



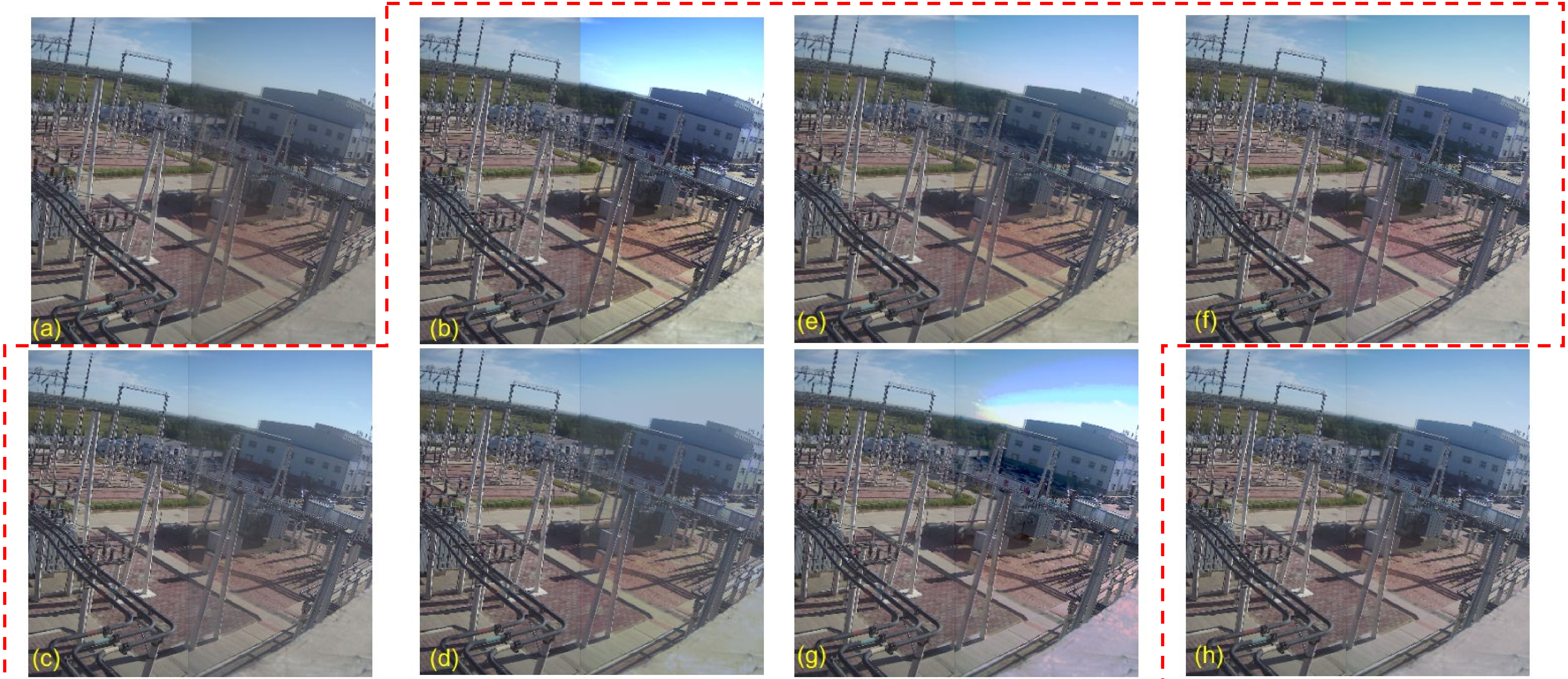
Processing:



4. Experiment and Results

Camera images

Other Methods

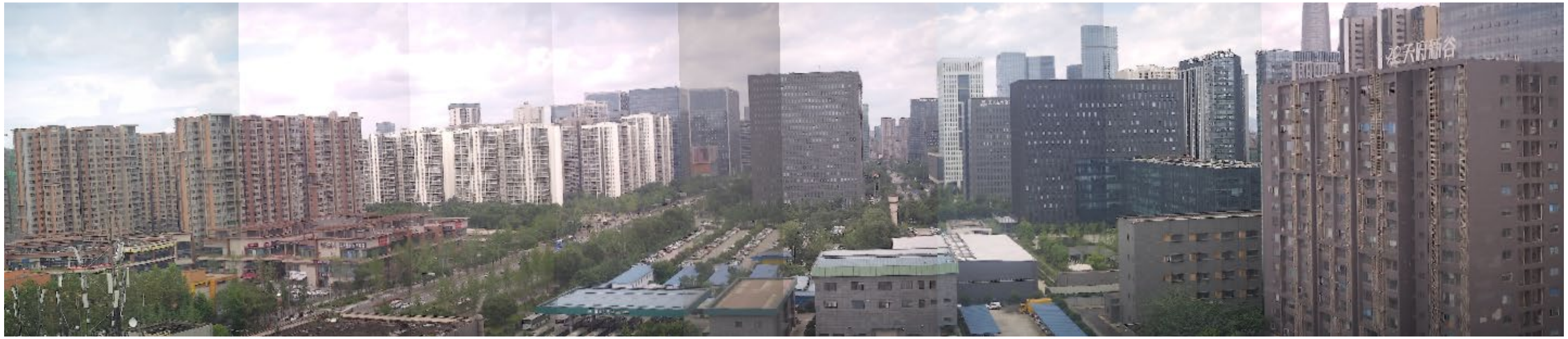


Our Method

4. Experiment and Results

☐ Result show

Before



After

4. Experiment and Results

- Objective evaluation

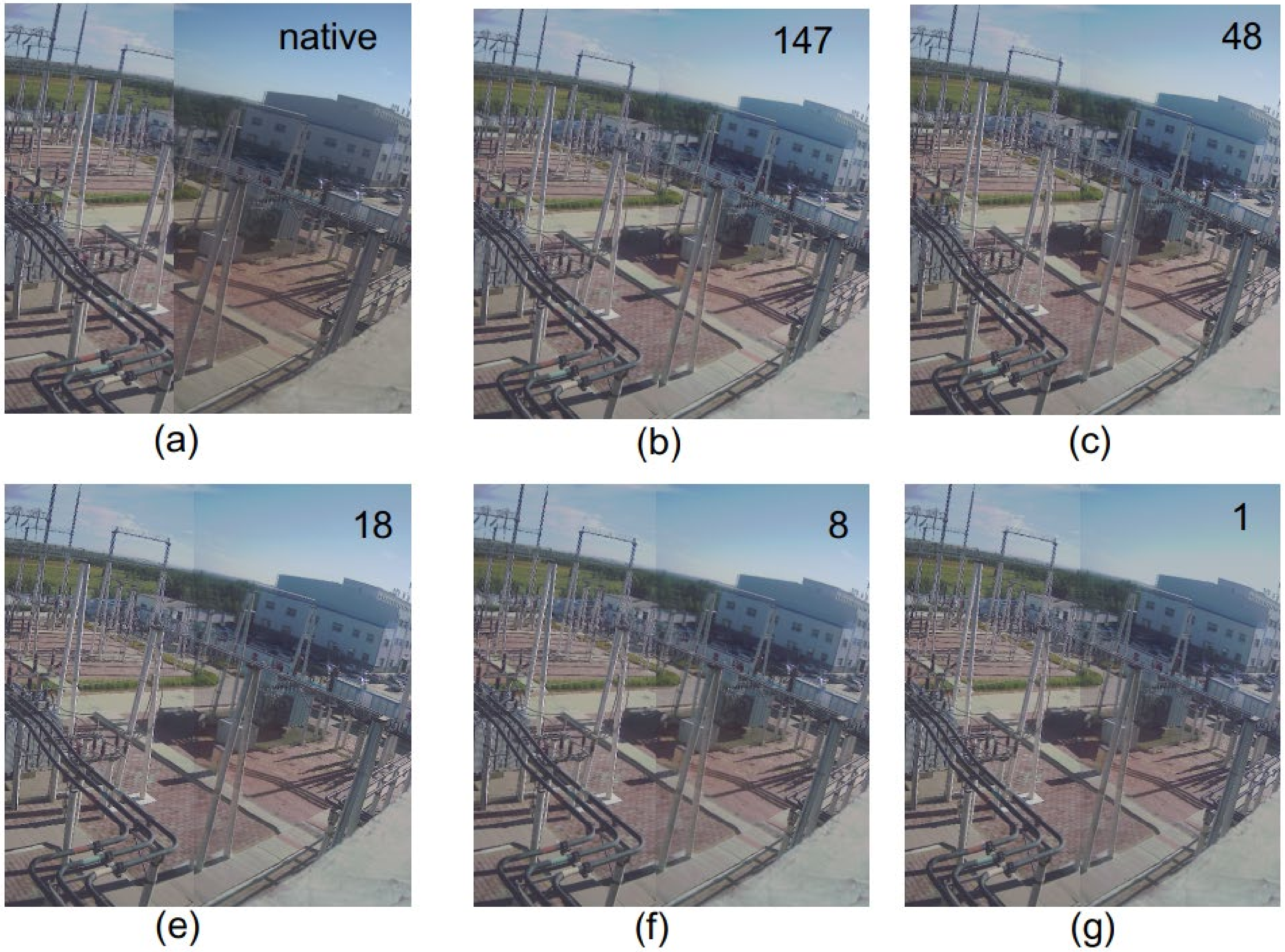
Best!

Method	PSNR↑	SSIM(%)↑	FSIM(%)↑	iCID(%)↓
R/GL [8]	24.37	85.78	92.22	24.31
AM/GL [12]	24.11	81.71	89.06	26.09
HM/GL [17]	26.67	86.88	93.16	20.36
G/GL [19]	24.32	83.38	89.92	25.39
3MS/GL [20]	24.41	82.74	89.55	26.90
FGPS/GL [15]	25.60	86.56	92.74	24.15
GPS/GL [15]	25.92	86.85	93.09	21.84
Prop. HHM_NS/GL	26.90	86.99	93.25	20.14
Prop. HHM/GL	26.94	87.07	93.32	19.97

5. Ablation studies

☐ Overlapped Pixels

Along with the decreasing of pixel-column, we can see that the color consistency after correction is gradually degraded.But it is still acceptable even when pixel-column = 1, in comparison to the native presentation before color correction .



5. Ablation studies

Ambient Light Consistency

(a) native image pair before color correction;
(b) color corrected rendering; Sampled snapshots from t1 to t5, ranging from the morning illumination to the dusk. Color mapping function is generated using snapshots captured at t1, and applied to all time instants. Red rectangles are extracted for final display.

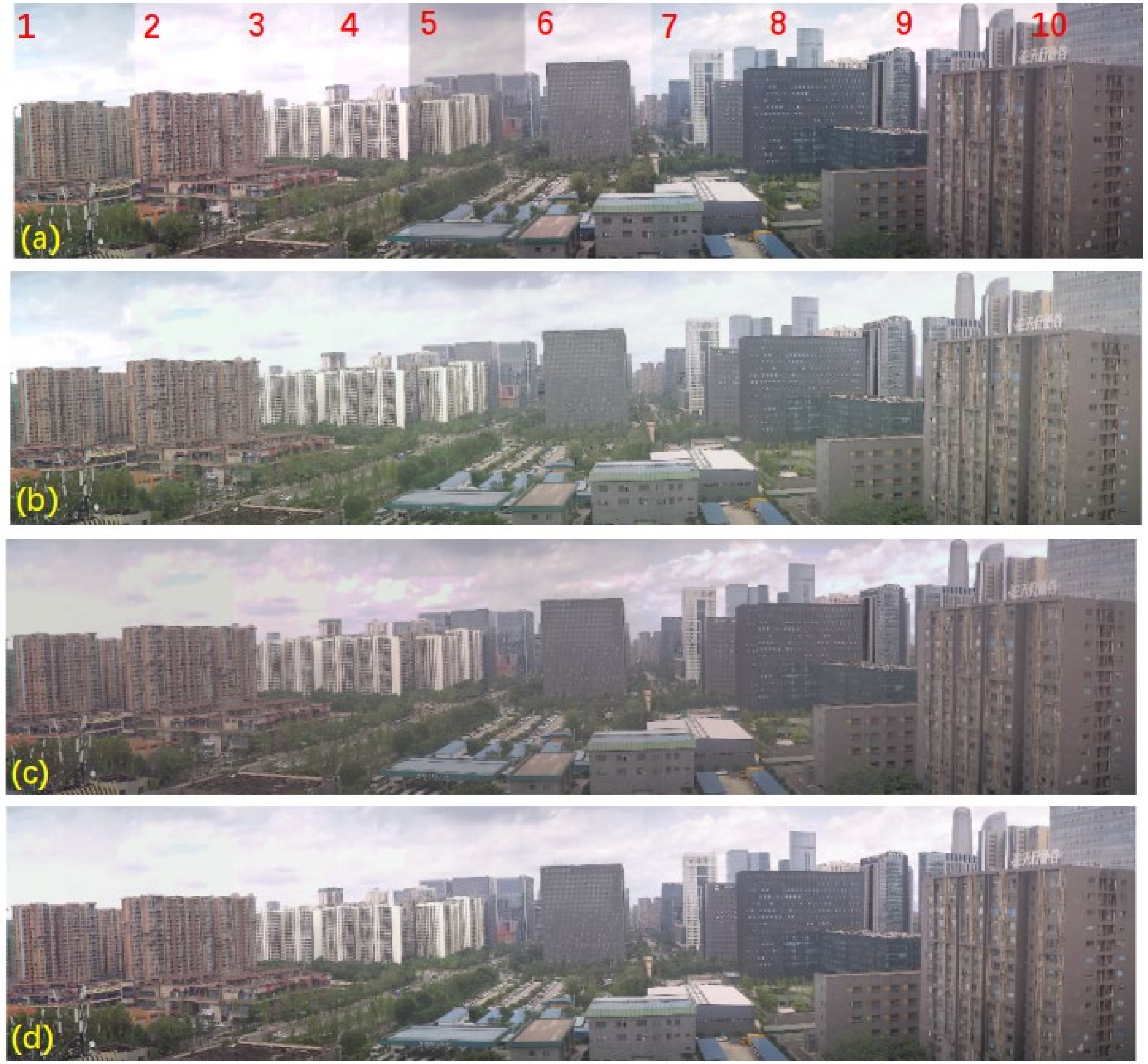
Our experiments have then shown that a single mapping function can be applied for a couple of hours, with satisfying image quality presentation. For a 24-hour duration, it just requires less than ten individual maps. This can be easily facilitated by updating the mapping function or lookup table on-the-fly.

5. Ablation studies

Multi-label Consistency

In a multi-camera system, we have the flexibility to choose different source labels for color correction.

We can utilized averaged mapping table for color transfer, as shown in (d) .Such averaging across different source labels could balance the image quality globally.



5. Ablation studies

Multi-Camera Imaging with Reference

Illustration of color correction using reference camera for Mantis 70 product. Color differences are effectively alleviated by applying the color correction using the reference camera as the source label (e.g., top versus bottom subplot).

6. Conclusion

- We have proposed the **hybrid histogram matching-based color correction** by integrating the global color mapping and local color straightening.
- Experimental studies using real multi-camera system (e.g., **self-built 10-camera prototype**, and commercialized Mantis 70) have revealed **superior efficiency** of our algorithm, in comparison to the existing popular approaches, with leading gains both objectively and subjectively.
- **Further ablation studies** have examined different aspects of proposed algorithm to understand its capacity in practical applications.

Thank you!