CV PROJECT REPORT

Color Homography Color Correction

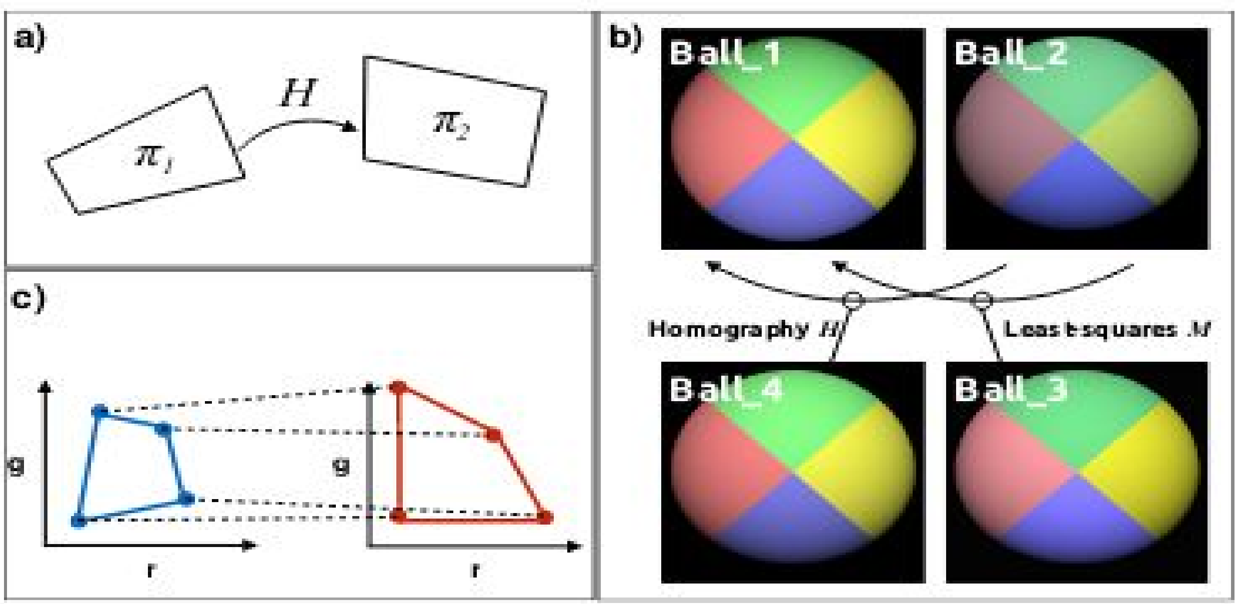
Team Name: SSK Team ID:17

Aim

- To show the surprising result that colors across a change in viewing condition (changing light color, shading and camera) are related by a homography.
- To evaluate Color Homography Color Correction methods like Alternating Least Squares Method, RANSAC Method, Least Square Method.

Motivation

- In geometry computer vision, an homography relates two planes.
- In color, an homography relates two photometric views.
- In this method, they proposed that to map one photometric view to another we must map the colors correctly independent of shading.
- Since shading only affects the brightness, or magnitude, of the RGB vectors, it is possible to find the 3×3 map which maps the color rays (the RGBs with arbitrary scalings) in one photometric view to corresponding rays in another.



Explanation of the above figure:

- We aspire to transfer color of Ball_1 to Ball_2. (Fig. b)
- Fig. c shows chromaticity diagrams of Ball_1 and Ball_2 being related by a Homography.
- Fig. a shows image planes being related by a chromaticity diagram.

Overview

- Introduction to Color Homography.
- Implementation of three algorithms for calculating Color Homography Color Correction. They are:
  - Least Square Color Correction
  - Alternating Least Squares Color Correction
  - RANSAC Color Correction
- Evaluation of the above Color Correction Algorithms using the following color spaces:
  - CIE L*a*b color space
  - CIE L*u*v color space
  - RGB color space
- Conclusion based on the above results as to which method is Algorithm gives more robust results.

Color Homography Theorem

Statement

- Chromaticities across a change in capture condition (light color, shading and imaging device) are a homography apart.

Proof

- First we assume that across a change in illumination or a change in device where the shading is the same the corresponding RGB's are related by a linear transform M
- Clearly, $H = CMC^{-1}$ maps colors in RGI form between illuminants.
- Due to different shading, the RGI triple under a second light is represented as c′ = α′ cH , where α′ denotes the unknown scaling.
- Without loss of generality let us interpret c as a homogeneous coordinate i.e. assume its third component is 1.
- Then, [r′ g′] = H ([r g]) (chromaticity coordinates are a homography H() apart).

Color Homography Color Correction Algorithms

1. Least square Color Correction

A is the input image matrix
B is the reference image matrix
A and B are reshaped to have the dimensions: [3, No. Of pixels in the image]
AM=B
We find M by using least squares method

2. Alternating Least Squares Color Correction

- Terminology
  - H- Homography Matrix (Captures Color Correction Component)
  - D- Shading Matrix (Captures Shading Correction Component)

Pseudo Code

- N - Number of pixels in the image
- A - nx3 matrix of RGB’s
- B - nx3 matrix of corresponding XYZ’s.
- D - nxn diagonal matrix of shading factors
- H - 3x3 color correction matrix
- Finally B can be computed as follows
  - **With shading correction** : from the equation DAH ≈ B
  - **Without shading correction** : DA ≈ B

$i = 0$, $\min_{D^0} \left\| D^0 A - B \right\|_F$, $A^0 = D^0 A$;
repeat
  $i = i + 1$;
  $\min_{H^i} \left\| A^{i-1} H^i - B \right\|_F$;
  $\min_{D^i} \left\| D^i A^{i-1} H^i - B \right\|_F$;
  $A^i = D^i A^{i-1} H^i$;
until $\left\| A^i - A^{i-1} \right\|_F < \epsilon$;

Results for ALS and LS Color Correction Algorithms

Image-1

A- input image
B- reference image
The other three images are
(1) A to B with shading correction
(2) A to B without shading correction
(3) A to B by least squares

Image-2

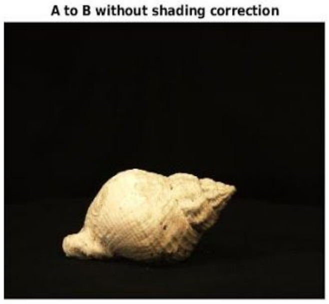
(1) Chromaticity diagram before applying homography. Purple -image B green-image A.
(2) Chromaticity diagram after applying just homography
(3) Chromaticity diagram after applying both homography and shading correction

A

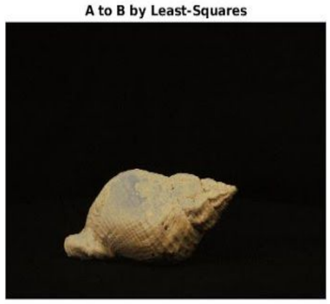
B

A to B with shading correction

A to B without shading correction

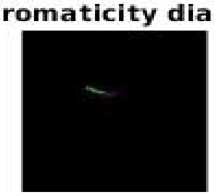


A to B by Least-Squares



origial chromaticity diag of both images

after using H chromaticity diag of both images



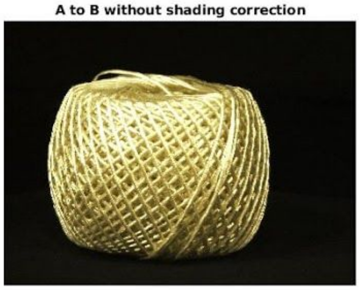
after using both H,D chromaticity diag of both images

A

B

A to B with shading correction

A to B without shading correction

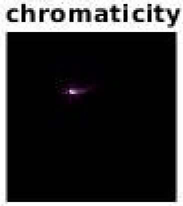


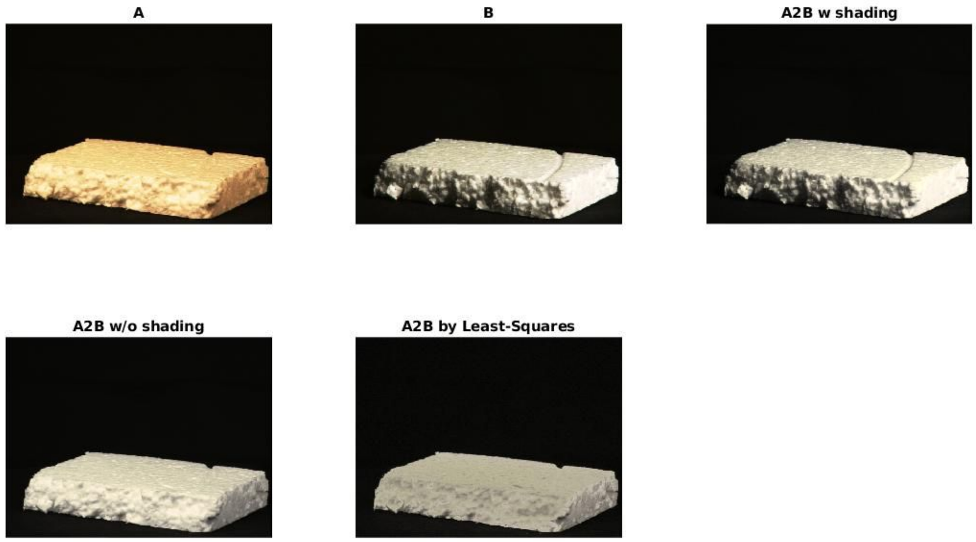
A to B by Least-Squares

origial chromaticity diag of both images

after using H chromaticity diag of both images

after using both H,D chromaticity diag of both images

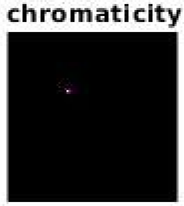


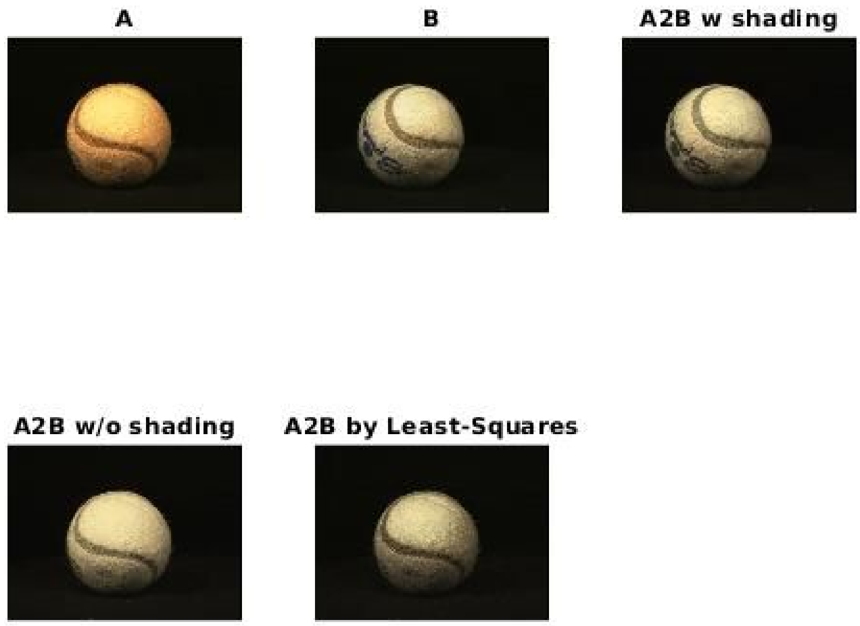


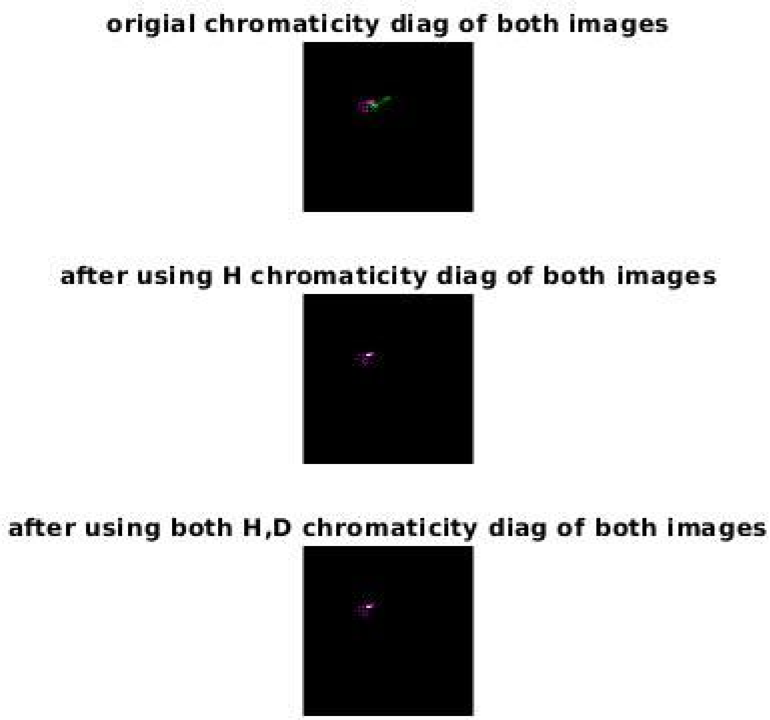
origial chromaticity diag of both images

after using H chromaticity diag of both images

after using both H,D chromaticity diag of both images




A
B
A2B w shading
A2B w/o shading
A2B by Least-Squares


origial chromaticity diag of both images
after using H chromaticity diag of both images
after using both H,D chromaticity diag of both images

A

B

A2B w shading

A2B w/o shading

A2B by Least-Squares

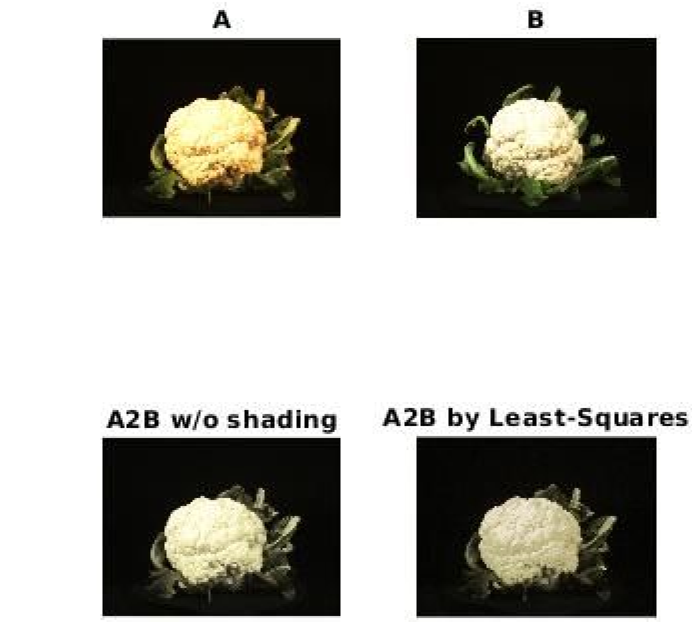
origial chromaticity diag of both images

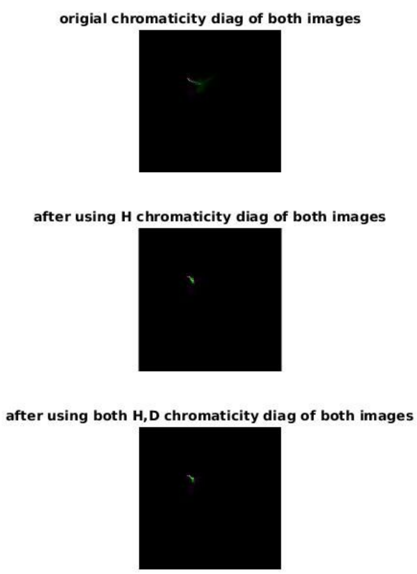
after using H chromaticity diag of both images

after using both H,D chromaticity diag of both images

Note:

- If we observe the mickey mouse images in Input A and Input B, we observe that mickey mouse in A is facing to the observers left and in B it is facing to the observers right.
- When we use color transformation using ALS Homography with shading correction, we can see structural differences in the Input Image A and reconstructed image along with color difference.
- This structural difference occurs because D (Shading Matrix), takes into account these structural differences as shading variation and not difference in images.
- In the reconstructed image using just ALS Homography matrix, mickey mouse is facing towards left as in Input A which is expected.
- But in the reconstructed image using ALS Homography matrix and Shading matrix, mickey mouse is facing towards right as in Input B which is not expected, because D matrix considers this structural change as shading.





Note:

- If we observe the cauliflower image Input A and Input B, both images are not exactly identical.
- When we use color transformation using ALS Homography with shading correction, we can see structural differences in the Input Image A and reconstructed image along with color difference.
- This structural difference occurs because D (Shading Matrix), takes into account these structural differences as shading variation and not difference in images.

A

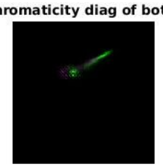
B

A2B w shading

A2B w/o shading

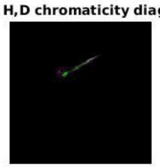
A2B by Least-Squares

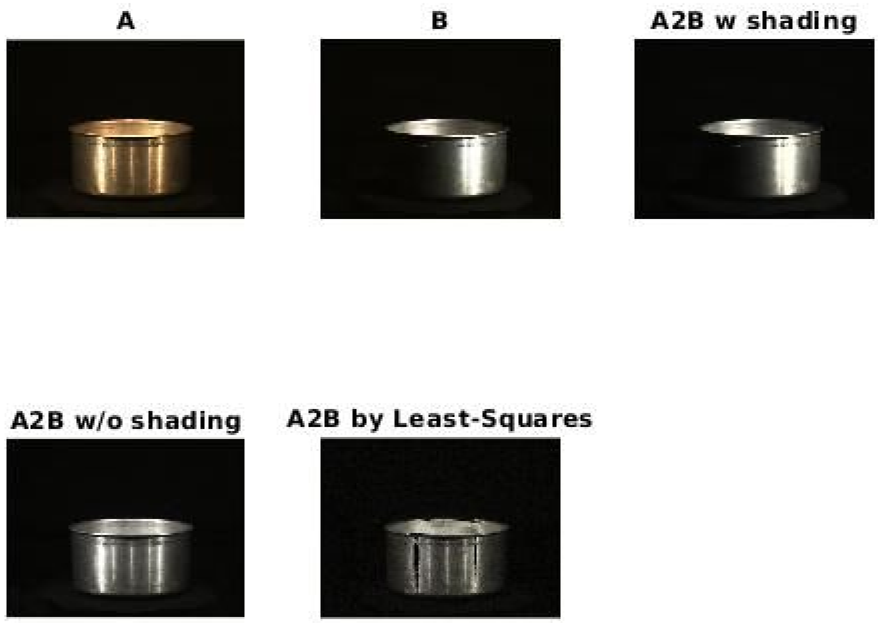
origial chromaticity diag of both images

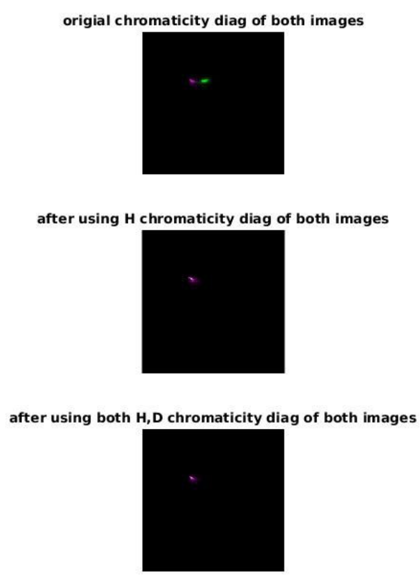


after using H chromaticity diag of both images

after using both H,D chromaticity diag of both images

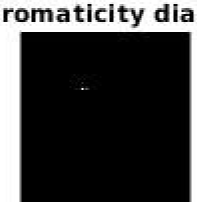



A
B
A2B w shading
A2B w/o shading
A2B by Least-Squares

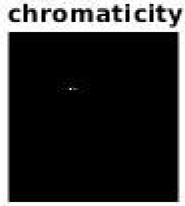

origial chromaticity diag of both images
after using H chromaticity diag of both images
after using both H,D chromaticity diag of both images

origial chromaticity diag of both images

after using H chromaticity diag of both images



after using both H,D chromaticity diag of both images



A

B

A2B w shading

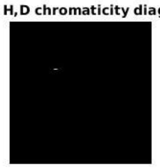
A2B w/o shading

A2B by Least-Squares

origial chromaticity diag of both images

after using H chromaticity diag of both images

after using both H,D chromaticity diag of both images



3. RANSAC Color Correction

Chromaticity Diagrams:

- They can be defined to have a size Nbin*Nbin
- Steps to compute Chromaticity Diagram of an image A:
    a. Resize A to have dimensions [3,Number of pixels]. Let this matrix be A’
    b. Convert RGB space to RGI space by multiplying A’ with C. Let B=CA’
    c. C=[1 0 1;0 1 1;0 0 1]
    d. Homogenise B by dividing R, G with I space.
    e. Construct a 1-d histograms for R and G space independently such that bin size of this histogram is 1/Nbin. Let these histograms be histR and histG.
    f. Now construct a 2-D matrix Chrodist of dimensions Nbin*Nbin such that Chrodist[i,j]=Number of pixels falling in the ith bin of histR and jth bin of histG.

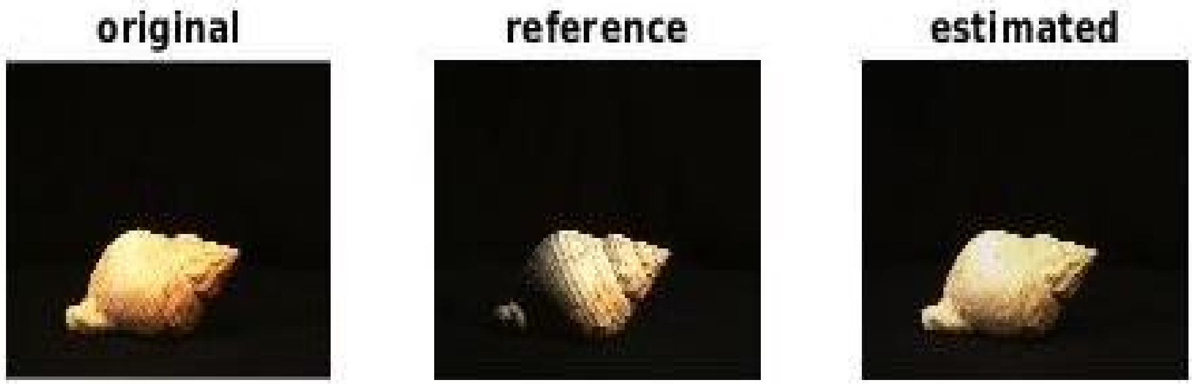
Pseudo Code:

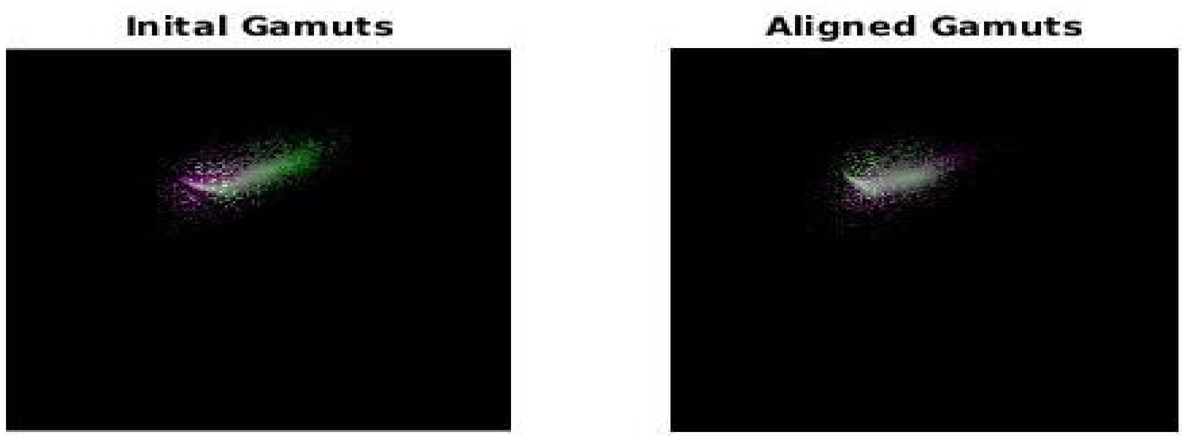
1. Input Image A to which color of Input Image B has to be transferred to form Image C
2. Construct Chromaticity diagrams of Image A and Image B as explained above.
3. Detect ASIFT features in chromaticity diagrams of Image A and B and find best matches. Smoothen Chromaticity diagrams of A and B to get required number of matches.
4. H matrix contains 9 variables (8 independent). Each match point gives 2 equations. Hence 4 match points are sufficient to find the Homography matrix.
5. We randomly choose 4 points out of the matched feature set.
6. We require at-least 3 points out of the 4 randomly chosen points to be non collinear to get a valid Homography matrix.This will ensure that all the 4 points are non-collinear. We check for this degeneracy of the set of 4 points using all possible combinations of 3 points from this set.
7. If we get a valid set we compute H using ALS algorithm.
8. We repeat steps 5-7 until convergence criteria is satisfied.
9. Convergence criteria is defined in the below two ways:
    a. If number of trials of RANSAC are greater than 5000 (OR)
    b. We define N = log(1-p)/log(pNoOutliers), where p=0.99 and pNoOutliers= #(outliers) / #(Total Points). We converge if N > #(trials so far)

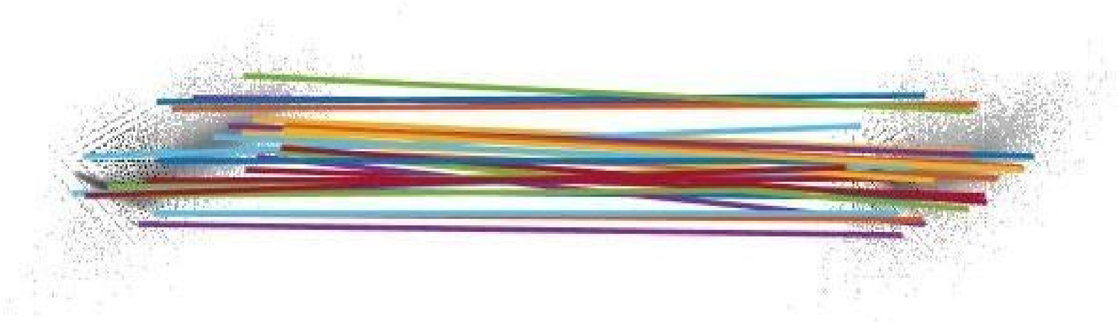
Note

- Computing Shading matrix (D) using RANSAC Color Correction with ALS as the fitting function will result in a D matrix of dimensions 4*4.
- In order to generate a shading correction matrix for the whole image, we require the dimensions of D to be Npixels*Npixels.
- Hence, shading correction cannot be done using RANSAC Algorithm.

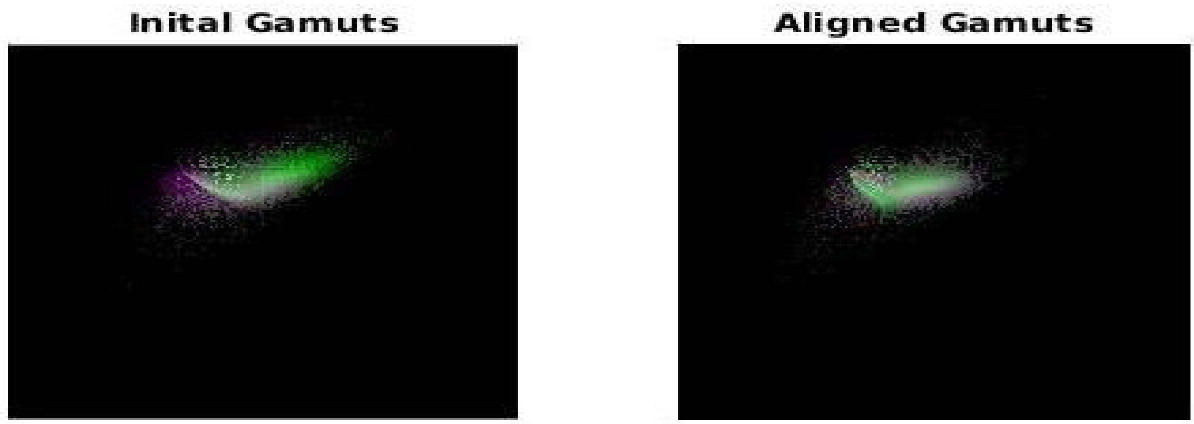
- **Results for Ransac:**

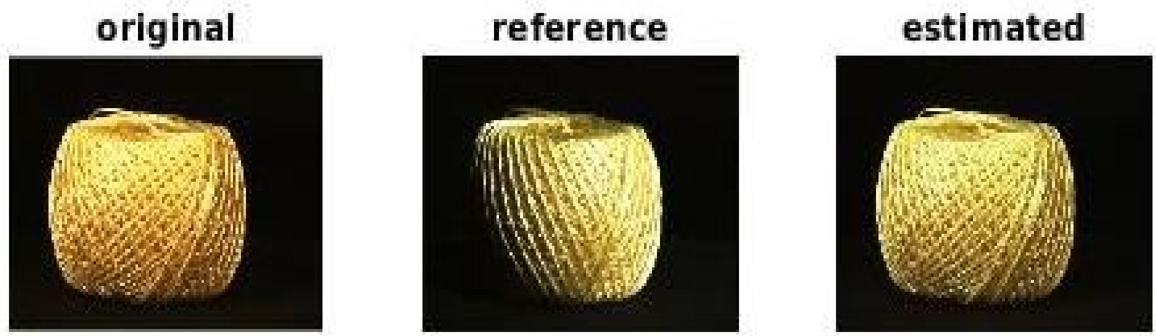


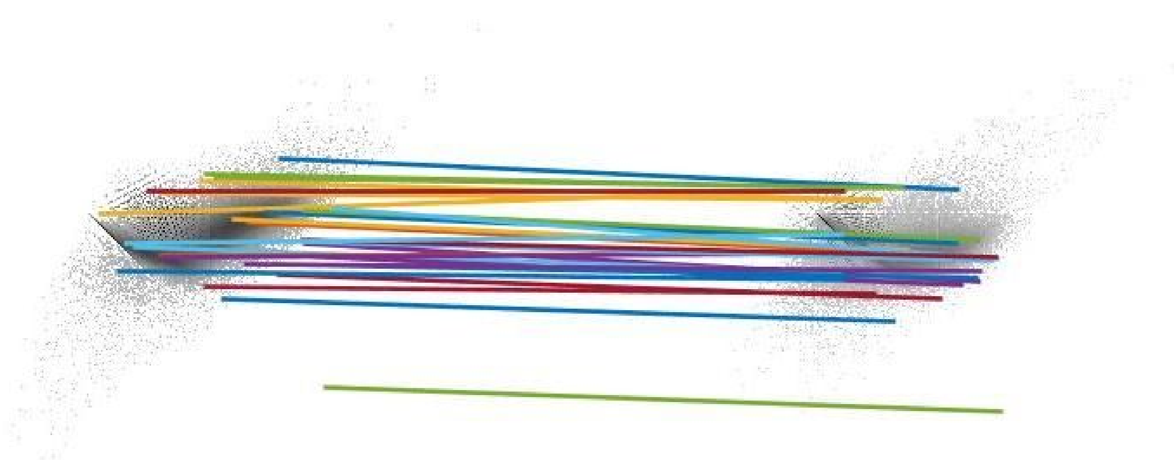




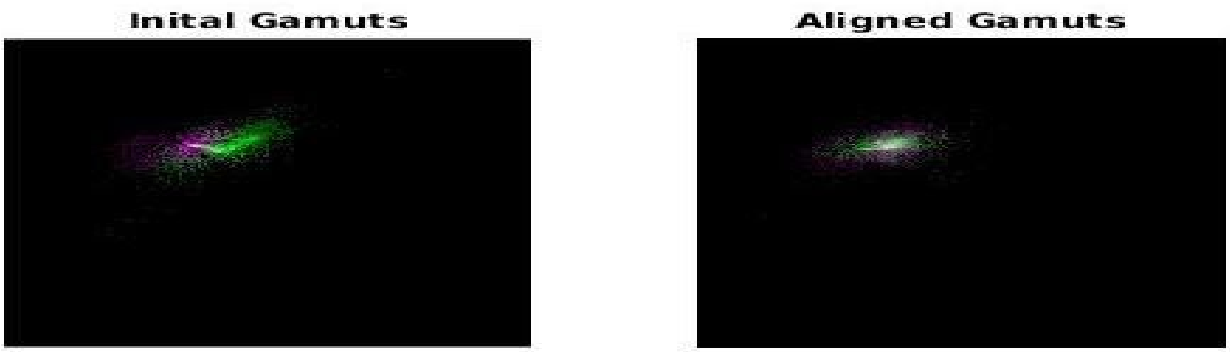
Matches in Chromaticity diagram using ASIFT



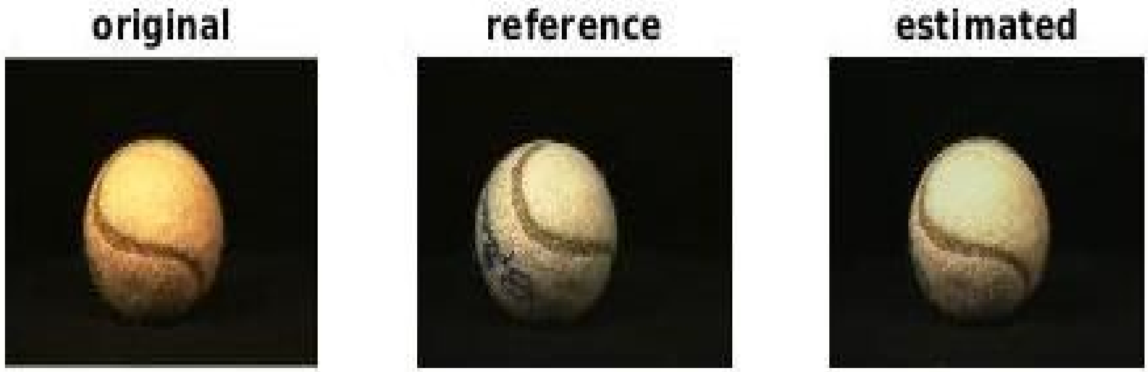


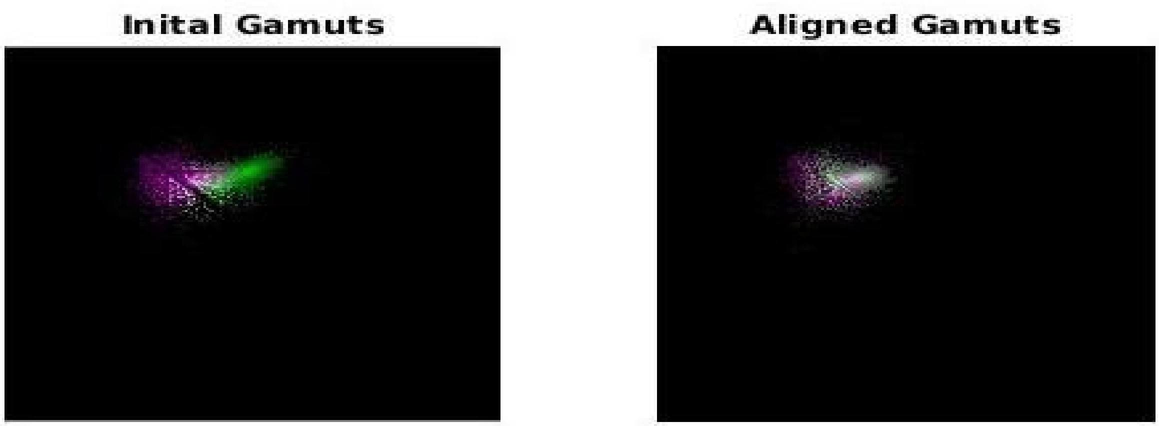


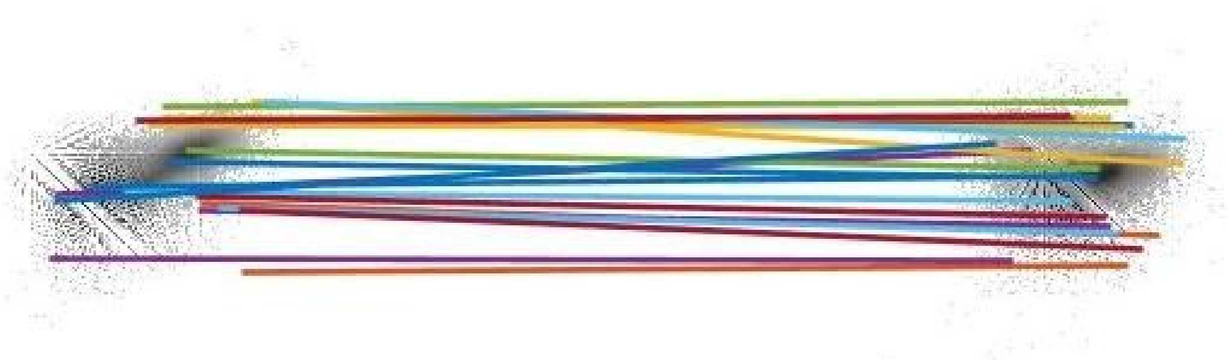
Matches in Chromaticity diagram using ASIFT



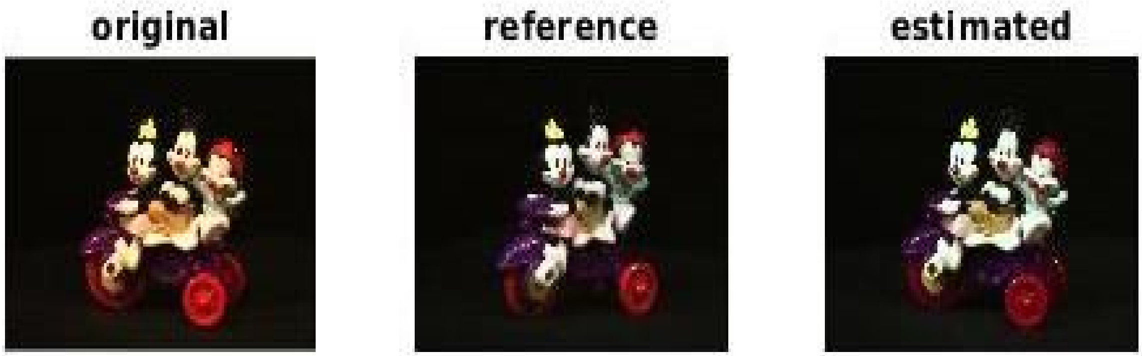
Matches in chromaticity diagrams using Asift

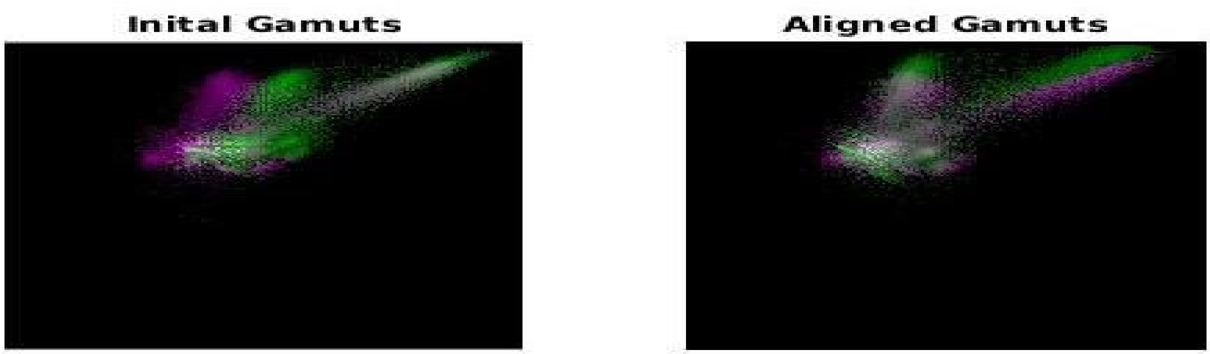


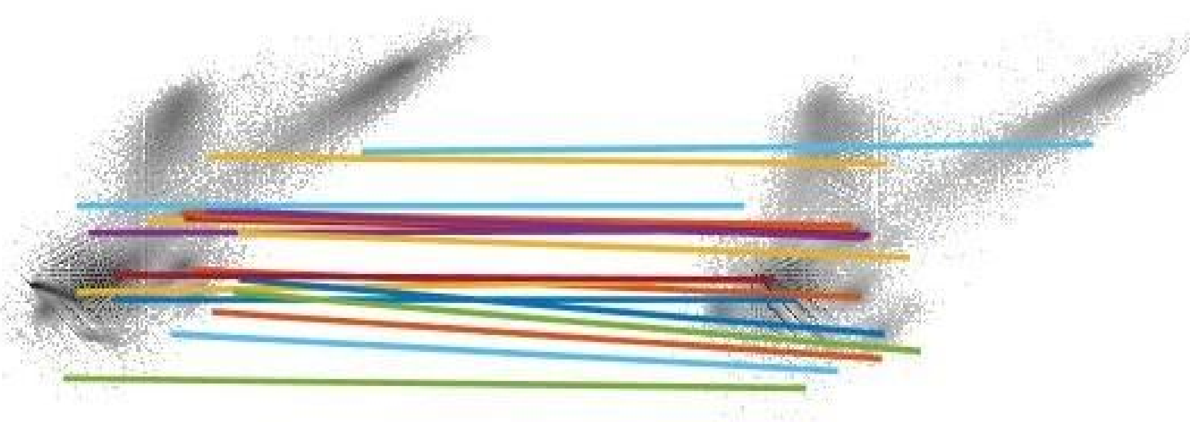




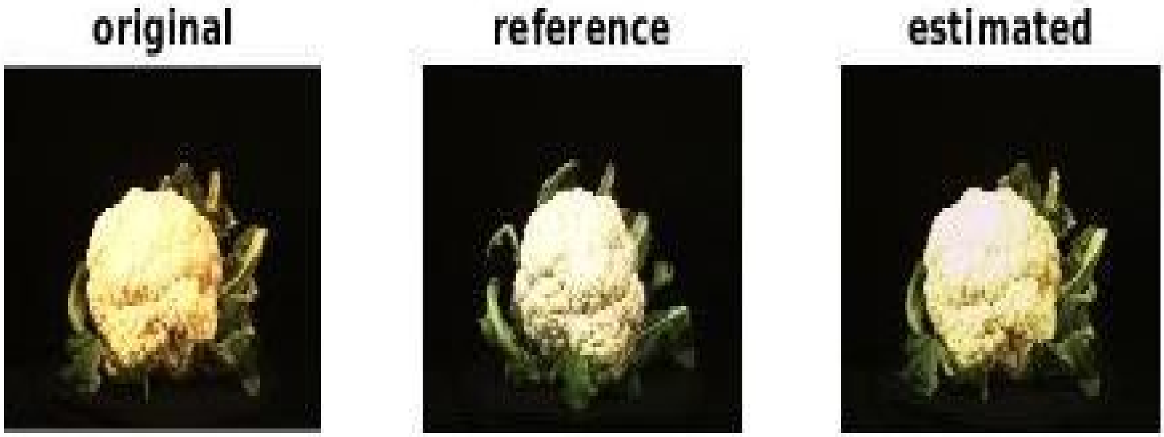
Matches in Chromaticity diagram using ASIFT

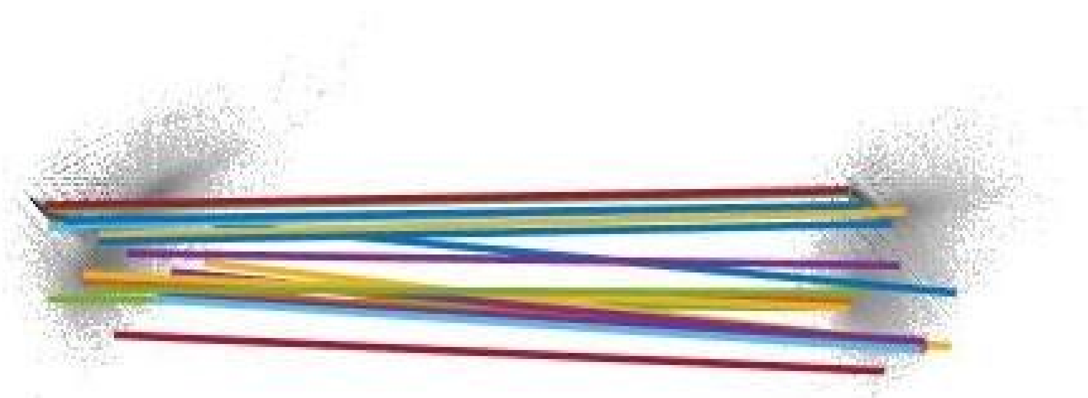




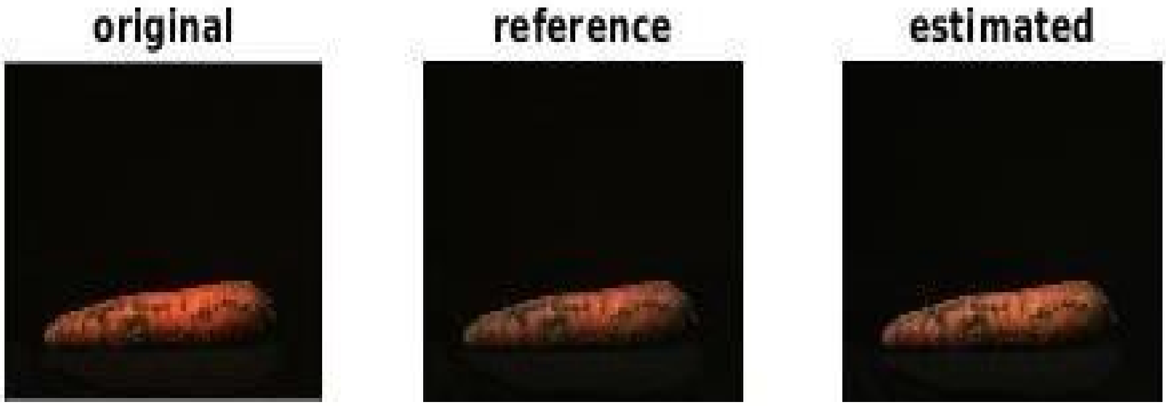


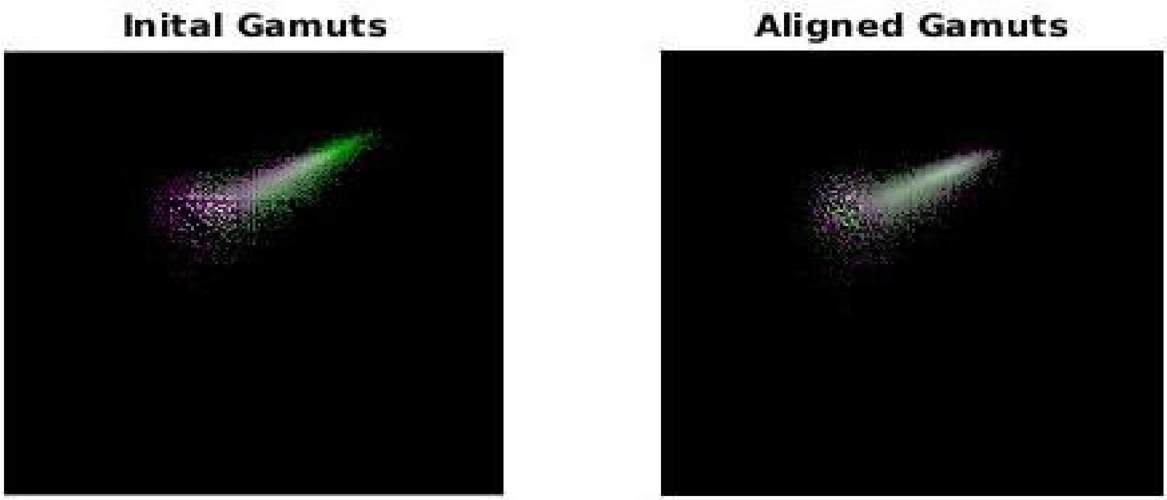
Matches in Chromaticity diagram using ASIFT



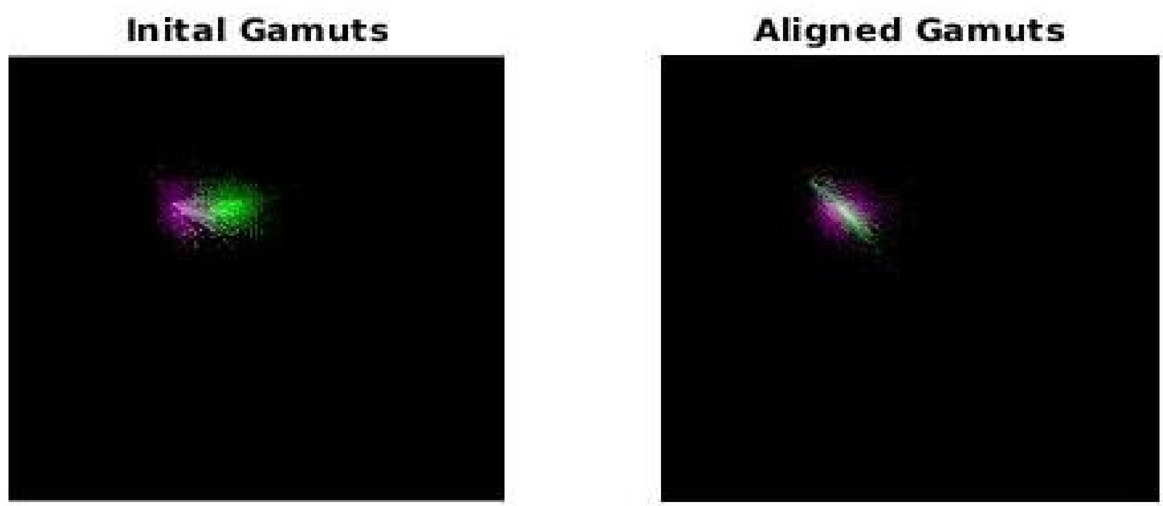


Matches in Chromaticity diagram using ASIFT





Matches in Chromaticity diagram using ASIFT



Matches in Chromaticity diagram using ASIFT

Comparing the results of Ransac and ALS:

- In Ransac the shading correction is not captured and the original structure of the input image is not affected whereas in ALS colour correction the shading is captured but the original structure of the input image is disturbed.

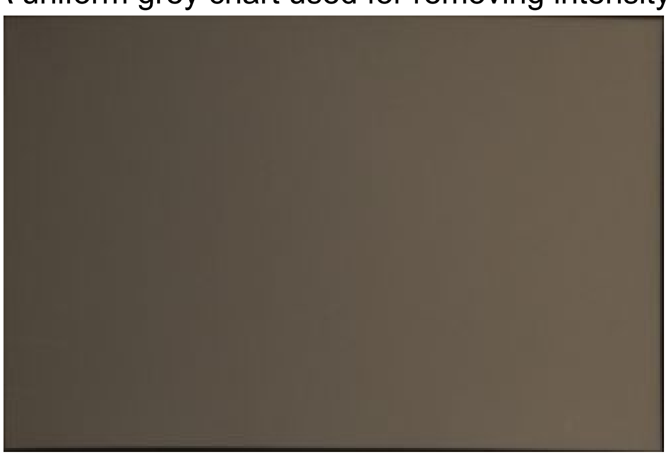
Evaluation Methods

- We wish to evaluate color correction when shading varies across the color target (in this case a Macbeth Color Checker).
- First we measure, in the lab, the actual ground truth XYZs. We call them ref_colors.
- Second we, in situ, measure the RGBs in a raw image where the shading can vary across the chart.
- We now solve directly for the correction matrix mapping the RGBs to XYZs.
- We apply the three computed correction matrices (least-squares, ALS, RANSAC and Root Polynomial) to the RGBs form the checker where the effects of intensity variation has been removed. This color is called sv_uniform.
- The intensity variation is removed by dividing by the brightness image of a uniform grey checker images in the same location in the same scene.
- The colors obtained without dividing by grey values are called sv_nonuniform.
- In evaluating our algorithms we will use RGB, CIE L*a*b* and CIE L*u*v*.
- We use a dataset of 13 images in which are 9 images are captured indoor and are 4 captured outdoor.
- The dataset also provides us with standard color values for both indoor and outdoor.
- We compute two kinds of homography matrices H_uniform and H_nonuniform by mapping ref_colors with sv_uniform and sv_nonuniform respectively, using least-squares, ALS and RANSAC algorithms.
- We use H_uniform and H_nonuniform on sv_uniform to get reconstructed reconstrcuted_ref_uniform and reconstrcuted_ref_nonuniform.
- The error between reconstrcuted_ref_uniform and ref_uniform in RGB, CIE L*a*b* and CIE L*u*v* color spaces gives uniform error in RGB, CIE L*a*b* and CIE L*u*v* spaces.
- The error between reconstrcuted_ref_nonuniform and ref_nonuniform in RGB, CIE L*a*b* and CIE L*u*v* color spaces gives non uniform error in RGB, CIE L*a*b* and CIE L*u*v* spaces.
- We even compared our results with another method called Root polynomial which is not mentioned in the paper .
- The RGB's are mapped to a standard colour space such as XYZ - useful for colour measurement- by a mapping function e.g. the simple 3×3 linear transform. This mapping, which we will refer to as LCC (linear colour correction), has been demonstrated above.An alternative and potentially more powerful method for colour correction is root polynomial colour correction (RPCC). Here, the R,GandB values at a pixel are extended by the polynomial terms.

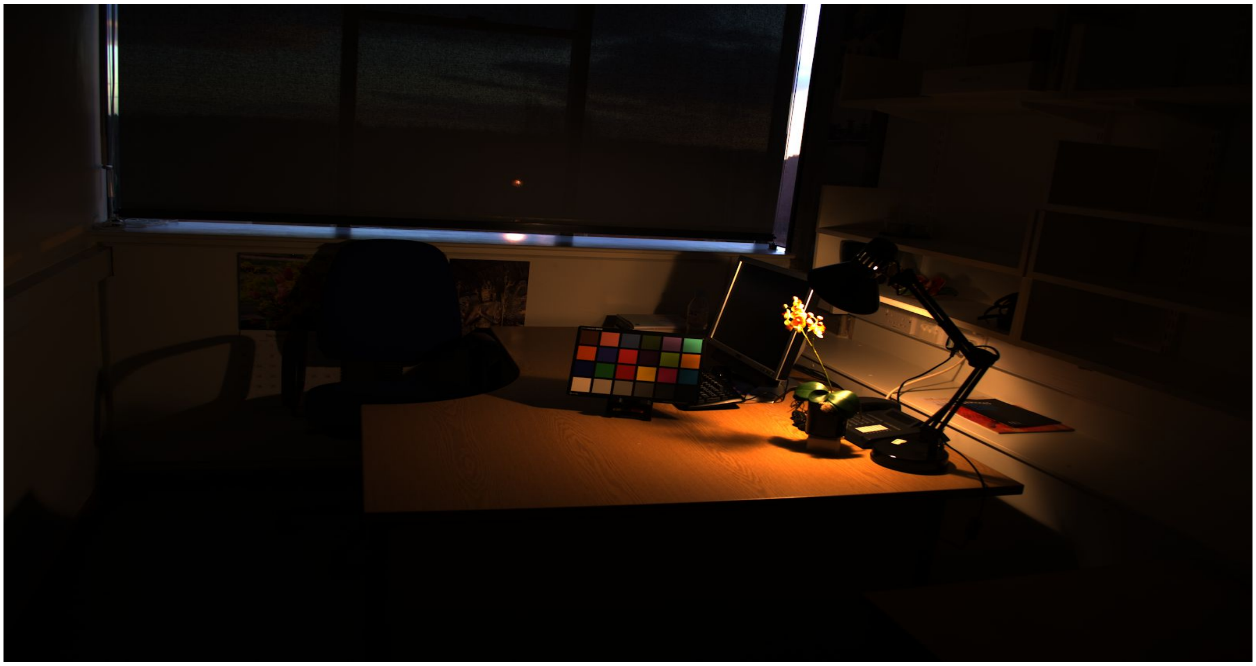
Macbeth Color checker Outdoor Images:

Just the Macbeth Color Checker Cropped

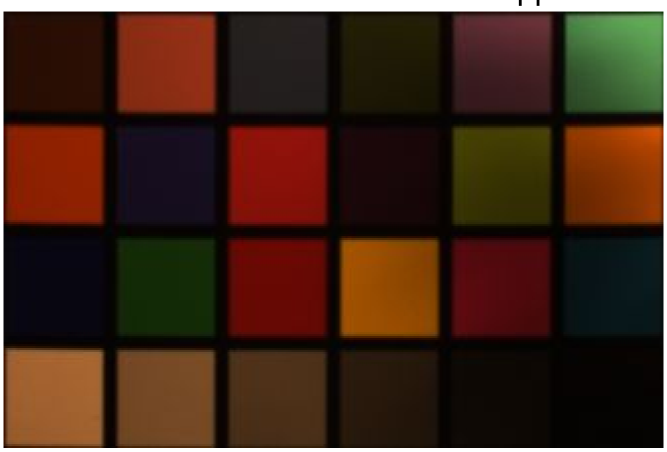
A uniform grey chart used for removing intensity variation



Macbeth Color checker Indoor Images:



Just the Macbeth Color Checker Cropped



A uniform grey chart used for removing intensity variation

- The actual ground truth XYZ’s for the Cloudy images: (24*3)

55.2932	51.5013	34.1946
168.8049	137.5587	32.2029
38.8573	33.2114	120.1809
380.2029	414.2129	398.1538
163.8523	155.1836	107.3277
65.8361	60.5818	173.5709
71.9976	117.4143	49.2004
248.6073	270.6497	272.9264
80.8573	89.6038	147.8040
129.1495	90.3575	63.4345
93.2629	60.4423	26.5652
155.9322	170.0556	172.7791
50.4446	64.2079	32.5813
41.5167	33.2643	65.5489
251.9290	274.1970	46.3682
85.0164	92.0874	93.1669
113.6929	111.4793	187.9539
154.8324	206.2811	54.5640
136.9638	92.3213	138.4716
40.5331	44.1930	45.8763
138.5231	195.8882	189.3401
204.2379	196.6661	38.4270
69.9051	97.9929	170.3417
17.3816	18.8311	19.8661

- The actual ground truth XYZ’s for the in images:(24*3)

56.5609	52.7016	35.8013
169.1144	138.3697	34.5155
40.3666	34.7302	122.7049
373.7998	406.0503	394.9597
163.9629	155.3200	109.6890
67.2632	61.9583	176.2856
72.8959	118.1088	51.5714
246.3554	267.3186	274.0968
81.9209	90.3640	150.4420
130.4345	91.7767	65.6318
95.3425	62.3332	28.5699
155.5547	169.0702	174.7915
51.3842	65.2261	34.2115
43.1066	34.8180	68.0494
250.3807	272.7233	48.6788
86.0638	92.9404	95.4401
114.6472	112.1249	190.3411
155.2531	206.3527	56.9795
137.9070	93.4378	141.0641
41.7531	45.3754	47.6346
138.4967	194.6521	191.3573
204.0535	197.0235	40.6066
70.9412	98.5281	172.3545
18.6981	20.1824	21.6442

We got these values directly from the dataset which we used to generate the above mean ,median,percentage 95 results.

Results obtained for Evaluation methods

RGB (Uniform)

	Mean	Median	pct95	Max
ALS	0.041623	0.027836	0.14813	0.24922
ALS_RANSAC	0.041547	0.026378	0.14929	0.25347
LS	0.061237	0.044642	0.17958	0.29625
RP	0.08557	0.057541	0.2789	0.33551

DeltaE LAB 1976 (Uniform)

	Mean	Median	pct95	Max
ALS	3.5484	2.8698	8.6401	9.5442
ALS_RANSAC	3.4298	2.6934	9.0717	10.194
LS	3.6672	3.178	8.2983	9.0491
RP	2.7682	2.0858	7.034	7.9857

DeltaE LUV (Uniform)

	Mean	Median	pct95	Max
ALS	4.0306	3.344	9.242	9.9202
ALS_RANSAC	3.8881	3.1339	9.6441	10.679
LS	4.0335	3.5371	8.9445	9.6683
RP	2.9904	2.5466	6.9428	8.8586

RGB (Non-Uniform)

	Mean	Median	pct95	Max
ALS	0.041623	0.027836	0.14813	0.24922
ALS_RANSAC	0.041547	0.026378	0.14929	0.25347
LS	0.061237	0.044642	0.17958	0.29625
RP	0.08557	0.057541	0.2789	0.33551

DeltaE LAB 1976 (Non-Uniform)

	Mean	Median	pct95	Max
ALS	3.548	2.8699	8.6391	9.5421
ALS_RANSAC	3.4174	2.6591	8.9944	10.32
LS	5.3935	4.7568	11.669	12.885
RP	6.6968	5.4794	20.437	25.8

DeltaE LUV (Non-Uniform)

	Mean	Median	pct95	Max
ALS	4.0295	3.3432	9.2387	9.9175
ALS_RANSAC	3.8805	3.0788	9.6856	10.794
LS	6.0887	5.7169	13.164	14.085
RP	7.005	6.3586	17.372	21.14

Analysis of the above obtained results

- The mean, median, 95% quantile and max ∆E errors are reported for RGB, CIE L*a*b* and CIE L*u*v* spaces using both uniform and non-uniform Homography matrices.
- It is clear that RANSAC- homography-based color correction supports a significantly improved color correction performance compared with the simple least square (all error measures are about 40% improved).
- Compared with the ALS color correction, all mean errors are improved by about 10%, and all median errors are improved by about 20%, at the cost of getting slightly higher 95% quantile error and maximum error.
- Hence, RANSAC-based color homography color correction is robust to outliers and delivers improved color fidelity.

Conclusion:

- The complete paper including the evaluation metrics has been implemented.
- We even compared our method with other methods such as root polynomial colour correction
- The results we obtained are almost similar to the results in the paper.

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