Digital Image Processing - CS 663

Group - 23

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Patch Based Filtering

Patch-based image **denoising approaches** can effectively reduce noise and enhance images. It takes a mean of all pixels in the image, weighted by how similar these pixels are to the target pixel.

In this question, we performed edge-preserving smoothing using **Patch Based Filtering**. The input images Intensities were scaled using ***im2double*** between 0 and 1. The basic algorithm involves adjusting pixel value for a particular pixel(p) by weighing it according to the extent of similarity between the patch around the pixel(p) and pixel(q) in a fixed window. To measure the similarity between the patched was accounted by a Gaussian scaling of ***L2 norm*** of difference of the patches.

In this question **window size** was **25x25** and **patch size** was **9x9**. To make the patch isotropic it was **Gaussian smoothed ($\sigma = 4$)** wrt distance. In case the patches being compared are of different sizes, the common area between the patch was considered. Hence only one tunable parameter, i.e. σ of the Guassian scaling function.

To speed up the algorithm, the images, barbara and honeycomb were first Gaussian blurred with $\sigma = 0.66$ and then sub-sampled by 2.
The values of the standard deviation were tuned on the basis of Root Mean Square Distance(RMSD), defined as:

$$RMSD(A, B) = \sqrt{\frac{\Sigma_p(A(p) - B(p))}{N}}$$

where A and B are the Original image and the Patch Based filter output image, N is the number of pixels and A(p) refers to a pixel in A.

The parameters were tuned manually using linear search, by first indexing over all the values in [0.1 1] for intensity and similar for distance. Then we zoomed onto the area having the minimum RMSD and increased the resolution, until we had a resolution of 2 decimal place. After this, the RMSD for various standard deviations(0.9 and 1.1 times the original) were computed as a proof to show that we had a minima.

Equations Used

For an image, Ω, and p and q are two points in image, $u(p)$ is the filtered image at point p. and $v(p)$ is the unfiltered image at point q.
Here, $R(p) \subseteq \Omega$ is a square region around the pixel p ans $|R(p)|$ is the number of pixels in that region.

$$
\begin{aligned}
u(p) &= \frac{1}{C(p)} \sum_{q \in \Omega} v(q) f(p,q) \\
C(p) &= \sum_{q \in \Omega} f(p,q) \\
f(p,q) &= \exp\{\frac{-|B(q) - B(p)|^2}{h^2}\} \\
B(p) &= \frac{1}{R(p)} \sum_{i \in R(p)} v(i)
\end{aligned}
$$

The Gaussian mask used in the patch of size 9×9 is shown below;

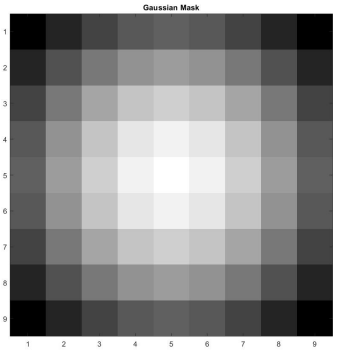

Figure 1: Gaussian Mask

1 Bilateral Filter Operation on images

1.1 Grass.png

Parameters used-

1. patch size = 9
2. window sie = 25
3. sigma(h) = 0.227
4. RSMD = 0.03140184181

Sigma	RMSD
0.2043	0.03238865109
0.227	0.03140184181
0.2497	0.03227763443

Table 1: RMSD for 0.9σ and 1.1σ

Sigma	RMSD
0.1	0.04602273913
0.2	0.03280277149
0.3	0.0383221143
0.4	0.05426617386
0.5	0.06732671191
0.6	0.07709034436
0.7	0.08463288777
0.8	0.09059065665
0.9	0.0953740742
1	0.09926227382

Sigma	RMSD
0.1	0.04602273913
0.11	0.04579223076
0.12	0.04525250478
0.13	0.04427936522
0.14	0.04287399727
0.15	0.041150011
0.16	0.03926029839
0.17	0.03735595521
0.18	0.03557390437
0.19	0.03402806854
0.2	0.03280277149
0.21	0.03195045958
0.22	0.0314918108
0.23	0.03141916578
0.24	0.03170298319
0.25	0.03229961332
0.26	0.03315927963
0.27	0.03423279001
0.28	0.0354756402
0.29	0.0368495064
0.3	0.0383221143

Sigma	RMSD
0.22	0.0314918108
0.221	0.03146751645
0.222	0.03144707876
0.223	0.03143047408
0.224	0.03141767668
0.225	0.03140865887
0.226	0.03140339105
0.227	0.03140184181
0.228	0.031403978
0.229	0.03140976478
0.23	0.03141916578
0.231	0.03143214308
0.232	0.03144865737
0.233	0.03146866799
0.234	0.03149213306
0.235	0.03151900948
0.236	0.03154925311
0.237	0.03158281879
0.238	0.03161966043
0.239	0.03165973112
0.24	0.03170298319

The output images are as shown:-

Figure 2: Original Image

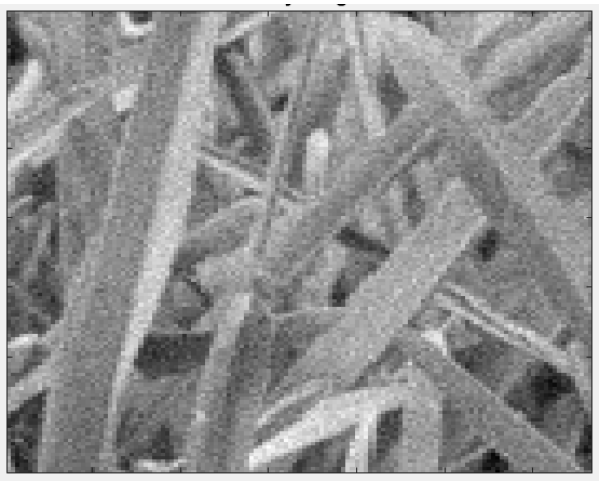

Figure 3: Noisy Image

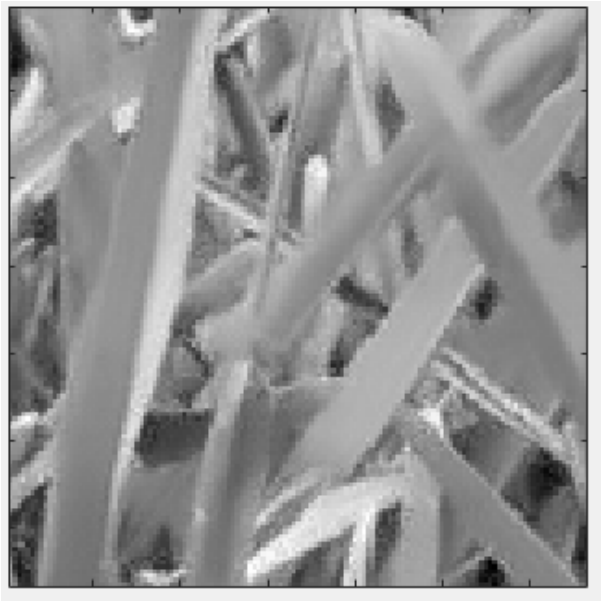

Figure 4: Patch Filtered Image

1.2 Barbara.mat

The image was first Gaussian blurred with $\sigma = 0.66$ and then sub-sampled by 2. Parameters used-

1. patch size = 9
2. window sie = 25
3. sigma(h) = 0.238
4. RSMD = 0.028345866

Sigma	RMSD
0.2142	0.02903988333
0.238	0.028345866
0.2618	0.02894403481

Table 2: RMSD for 0.9σ and 1.1σ

Sigma	RMSD
0.1	0.04658553075
0.2	0.03022262513
0.3	0.03157682283
0.4	0.04090743904
0.5	0.04913876023
0.6	0.0560769384
0.7	0.06226587058
0.8	0.06803497462
0.9	0.07348783758
1	0.07861601056

Sigma	RMSD
0.15	0.038836851
0.16	0.036746017
0.17	0.034747677
0.18	0.032951918
0.19	0.031432681
0.2	0.030222625
0.21	0.029325706
0.22	0.02873005
0.23	0.028414586
0.24	0.028352195
0.25	0.028512281

Sigma	RMSD
0.23	0.028414586
0.231	0.028397445
0.232	0.028382807
0.233	0.028370644
0.234	0.028360924
0.235	0.028353617
0.236	0.028348692
0.237	0.028346119
0.238	0.028345866
0.239	0.028347902
0.24	0.028352195
0.241	0.028358713
0.242	0.028367426
0.243	0.028378301
0.244	0.028391306
0.245	0.028406409
0.246	0.028423578
0.247	0.028442782
0.248	0.028463989
0.249	0.028487165
0.25	0.028512281

The output images are as shown:-

Figure 5: Original Image

Figure 6: Noisy Image

Figure 7: Patch Filtered Image

1.3 HoneyCombReal.png

The image was first Gaussian blurred with $\sigma = 0.66$ and then sub-sampled by 2. Parameters used-

1. patch size = 9
2. window sie = 25
3. sigma(h) = 0.24
4. RSMD = 0.03602486025

Sigma	RMSD
0.216	0.03701297522
0.24	0.03602486025
0.264	0.0369126747

Table 3: RMSD for 0.9σ and 1.1σ

Sigma	RMSD
0.1	0.04692005032
0.2	0.03864398277
0.3	0.04107072922
0.4	0.05871804924
0.5	0.07304114734
0.6	0.08275435122
0.7	0.08940644212
0.8	0.09413683092
0.9	0.09763878772
1	0.1003220187

Sigma	RMSD
0.1	0.04692005032
0.11	0.04665662719
0.12	0.04624074575
0.13	0.04574871164
0.14	0.04520178505
0.15	0.04453168731
0.16	0.04366039895
0.17	0.04256173858
0.18	0.0412815144
0.19	0.03992962354
0.2	0.03864398277
0.21	0.03754588718
0.22	0.03671771902
0.23	0.03620477721
0.24	0.03602486025
0.25	0.03617626174
0.26	0.03664314158
0.27	0.03739958627
0.28	0.03841334871
0.29	0.03964912915
0.3	0.04107072922

Sigma	RMSD
0.23	0.03620477721
0.231	0.03617169577
0.232	0.03614196587
0.233	0.03611559116
0.234	0.03609257352
0.235	0.0360729131
0.236	0.03605660837
0.237	0.0360436562
0.238	0.03603405187
0.239	0.03602778912
0.24	0.03602486025
0.241	0.03602525608
0.242	0.03602896607
0.243	0.03603597831
0.244	0.0360462796
0.245	0.03605985543
0.246	0.0360766901
0.247	0.03609676669
0.248	0.03612006713
0.249	0.03614657223
0.25	0.03617626174

The output images are as shown:-

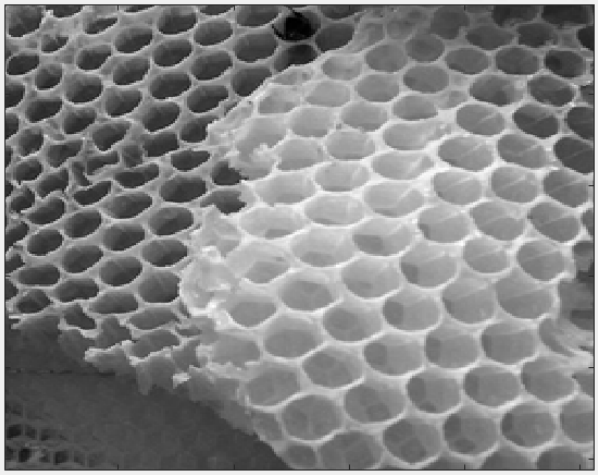

Figure 8: Original Image

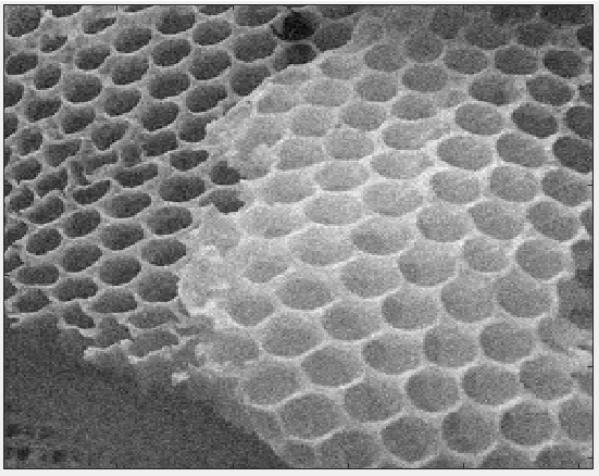

Figure 9: Noisy Image

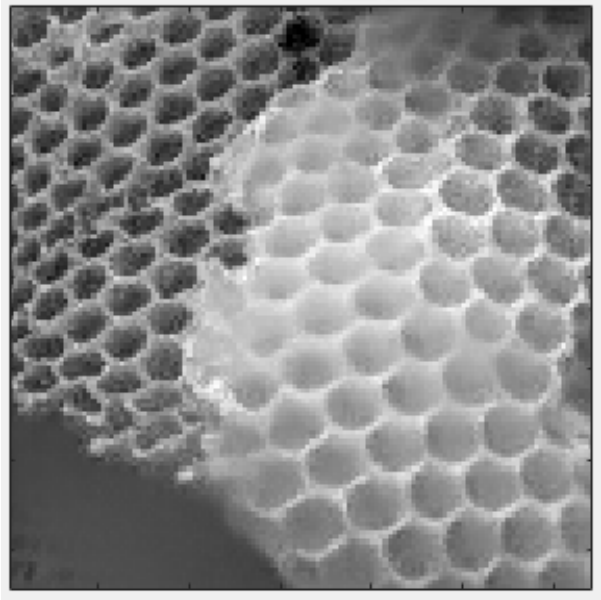

Figure 10: Patch Filtered Image

2 Results

- Grass.png $\sigma = 0.227$, RMSD = 0.03140184181
- Barbara.mat $\sigma = 0.238$, RMSD = 0.028345866
- HoneyCombReal.png $\sigma = 0.24$, RMSD = 0.03602486025