EECS 442: Computer Vision, Winter 2017

Homework 1: Color images

Due date: January 24 by 11:59 PM

Overview

In this homework you will learn some basics for manipulating images in MATLAB.

This is a two part homework. In the first part you will align red, green, and blue channels to recreate a set of historic images in full color. In the second part you will implement demosaicing algorithms to capture color in the same manner as a digital camera.

Part 1: Coloring Prokudin-Gorskii images

Sergei Mikhailovich Prokudin-Gorskii was a color photographer far ahead of his time. He undertook a photographic survey of the Russian Empire for Tsar Nicholas II and was able to capture color pictures before color cameras were invented. His idea was to take three pictures of each scene using a red, green, and blue color filter. These images could then be combined to obtain the full color photograph. There was no way of printing these back in the day, so he envisioned complex devices to display the final image. Though these devices were never made, his pictures survived. In this homework you will reconstruct the color images from scans of his photographs.

The key step here is to align the different color channels. Since the camera moved between each shot, these channels are slightly offset from each other. The simplest way to fix this is to keep one channel fixed say red, and align the green and blue channels to it by searching over displacements in a fixed range. Pick the displacement that maximizes similarity between the channels. One such measure is dot product, i.e, `R'G`. Another is normalized cross-correlation, which is the dot product after l2 normalization.

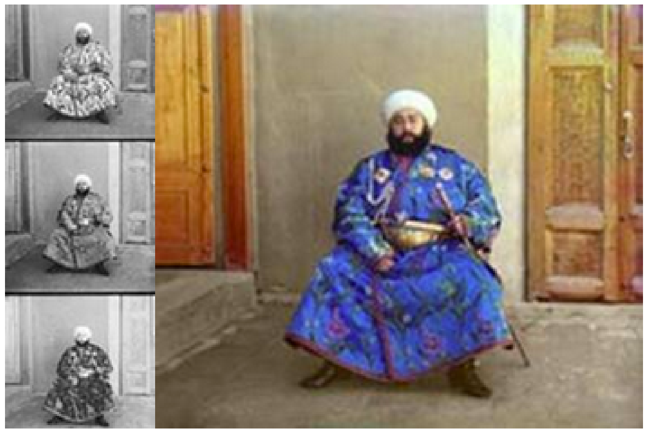

Figure 1: Example image from the Prokudin-Gorskii collection. Note the colors are in B, G, R order from top to bottom (not R, G, B)

Before you start aligning the Prokudin-Gorskii images, you will test your code on synthetic images which have been randomly shifted. Your code should correctly discover the inverse of the shift.

Code

Run `evalAlignment.m` on the MATLAB command prompt inside the code directory. This should produce the following output.

Note the actual 'gt shift' might be different since it is randomly generated.

```
Evaluating alignment ..
1 balloon.jpeg
       gt shift: ( 1,11) ( 4, 5)
     pred shift: ( 0, 0) ( 0, 0)
2 cat.jpg
       gt shift: (-5, 5) (-6,-2)
     pred shift: ( 0, 0) ( 0, 0)
 ...
```

The code loads a set of images, randomly shifts the color channels, and provides them as input to the function `alignChannels`. You must implement this function. A correct implementation should obtain shifts that are the negative of the ground-truth shifts, i.e., the following output:

```
Evaluating alignment ..
1 balloon.jpeg
       gt shift: ( 13, 11)  ( 4, 5)
     pred shift: (-13,-11)  (-4,-5)
2 cat.jpg
       gt shift: (-5, 5) (-6,-2)
     pred shift: ( 5,-5) ( 6, 2)
 ...
```

Once you are done with that, run `alignProkudin.m`. This will call your function to align images from the Prokudin-Gorskii collection. The output is saved automatically. In your report, show all the aligned images as well as the shifts that were computed by your algorithm. It is possible that your solution will not perfectly align every single image, please explain why you think certain images fail.

Tips: Look at functions `circshift()` and `padarray()` to deal with shifting images.

Extra credit

Here are some ideas for extra credit:

- **Boundary effects**: Shifting images causes ugly boundary artifacts. Come up with of a way of avoiding this.
- **Faster alignment**: Searching over displacements can be slow. Think of a way of aligning them faster in a coarse to fine manner. For example you may align the channels by resizing them to half the size and then refining the estimate. This can be done by multiple calls to your `alignChannels()` function.
- **Gradient domain alignment**: Instead of aligning raw channels, you might want to align the edges to avoid overdue emphasis on constant intensity regions. You can do this by first computing an edge intensity image and then using your code to align the channels. Look at the `edge()` function in Matlab.

Part 2: Color image demosaicing

Recall that in digital cameras the red, blue, and green sensors are interlaced in a Bayer pattern. Your goal is to fill the missing values to obtain a 3-channel color image. You will implement several different interpolation algorithms. The input to the algorithm is a single image `im`, an `NxM` array of numbers between 0 and 1. These are measurements in the format shown in Figure 2, i.e., top left `im(1,1)` is red, `im(1,2)` is green, `im(2,1)` is green and `im(2,2)` is blue channel. Your goal is to create a single color image C from these measurements.

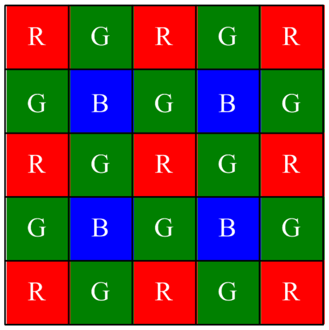

Figure 2: Bayer pattern

Start with some non-adaptive algorithms. Implement *nearest neighbor* and *linear* interpolation algorithm. Then implement an adaptive algorithm such as *weighted gradient averaging*. Compare the results. Where are the errors? (For the adaptive gradient approach, if you search Google you will find different methods that are more sophisticated than what we are asking you to do. One of the posted slides from lecture has the information on what we are looking for)

Evaluation

We will evaluate the algorithm by comparing your output to the ground truth color image. The input to the algorithm was constructed by artificially mosaicing it. This is not ideal in practice, since there is a demosaicing algorithm that was used to construct the digital image in the first place, but we will ignore this for now. The mean error is computed between each color image and your output, please report these numbers for each algorithm.

Code

Run `evalDemosaicing` on the MATLAB command prompt inside the code directory. You should be able to see the output shown in Figure 3. The code loads images from the data directory, artificially mosaics them, and provides them as input to the demosaicing algorithms. The actual code for that is in `demosaicImage.m` file. Right now only the `demosaicImage(im, 'baseline')` is implemented. All the other methods call the baseline methods which is why they produce identical errors. Your job is to implement the following functions in the file:

- `demosaicImage(im, 'nn')` - nearest-neighbour interpolation.
- `demosaicImage(im, 'linear')` - linear interpolation.
- `demosaicImage(im, 'adagrad')` - adaptive gradient interpolation.

The baseline method achieves an average error of 0.1392 across the 10 images in the dataset. Your methods you should be able to achieve substantially better results. As a reference, the linear interpolation method achieves an error of about 0.0174. *You should report the results of all your methods in the form* *of the same table.*

```
---------------------------------------------------------------------------------
#       image           baseline        nn              linear          adagrad
---------------------------------------------------------------------------------
1       balloon.jpeg    0.179239        0.179239        0.179239        0.179239
2       cat.jpg         0.099966        0.099966        0.099966        0.099966
3       ip.jpg          0.231587        0.231587        0.231587        0.231587
4       puppy.jpg       0.094093        0.094093        0.094093        0.094093
5       squirrel.jpg    0.121964        0.121964        0.121964        0.121964
6       candy.jpeg      0.206359        0.206359        0.206359        0.206359
7       house.png       0.117667        0.117667        0.117667        0.117667
8       light.png       0.097868        0.097868        0.097868        0.097868
9       sails.png       0.074946        0.074946        0.074946        0.074946
10      tree.jpeg       0.167812        0.167812        0.167812        0.167812
---------------------------------------------------------------------------------
        average         0.139150        0.139150        0.139150        0.139150
---------------------------------------------------------------------------------
```

Figure 3: Output of `evalDemosaicing.m`

Tips: You can visualize at the errors by setting the display flag to true in the `runDemosaicing.m`. Avoid loops for speed in MATLAB. Be careful in handling the boundary of the images. It might help to think of various operations as convolutions. Look up MATLAB's `conv2()` function that implements 2D convolutions.

Extra credit

Here are some ideas for extra credit:

- **Transformed color spaces:** Try your previous algorithms by first interpolating the green channel and then transforming the red and blue channels R ← R/G and B ← B/G, i.e., dividing by the green channel and then transforming them back after interpolation. Try other transformations such as logarithm of the ratio, etc (*note: you have to apply the appropriate inverse transform*). Does this result in better images measured in terms of the mean error? Why is this a good/bad idea?
- **Digital Prokudin-Gorskii:** Imagine that Prokudin was equipped with a modern digital camera. Compare the resulting demosaiced images to what he obtained using his method of taking three independent grayscale images. Start with the aligned images of your first part and create a mosaiced image by sampling the channels image using the Bayer pattern. Run your demosaicing algorithms and compare the resulting image with the input color image. How much do you lose? Where are the errors?

Writeup

You are required to turn in a writeup briefly describing your results. Include example images of the output obtained from each part. The writeup should be self contained, describing the key choices you made. Do some analysis on what works and what doesn't with these methods. If you do any of the suggested extra credit, explain clearly, and include any quantitative or qualitative results you obtained.

Although, this is the primary way in which you will be evaluated you are also required to turn in code for your experiments. For this homework only the functions `alignChannels.m` and `demosaicImage.m` should be changed.

Submission

What to submit? To get full credit for this homework you should include the following files in your Canvas submission:

- The write up preferably as a pdf file.
- Code for part 1, the file `alignChannels.m`
- Code for part 2, the file `demosaicImage.m`

Any extra credit items you have done should also be described in the report and the appropriate code must also be included to recieve full credit.

Acknowledgements

This homework is taken from the class CMPSCI 670 at University of Massachusetts, Amherst put together by Subhransu Maji, and is partly based on a similar one made by Alyosha Efros.