Image Haze Removal Using Dark Channel Prior

Dear teachers and fellow students, good morning! My name is Zhuowen Lin and I am majoring in Information Engineering.

The topic of my project is “image haze removal using dark channel prior”. Haze is something like fog, formed by small particles, floating within the air and blurring your perspective.

The outline of my speech is listed here. First, I will introduce the basic techniques about the dark channel prior image dehazing method. Then, I will demonstrate the result of my program based on the techniques. Then, I will show my analyses of the performances for different parameters in algorithm. The last part, of course, is Q&A. So, let’s start.

In previous largely acknowledged studies of atmospheric light, a hazy image can be mathematically modeled as , in which is the observed hazy image by the camera, is the haze-free image, or we can say it as the actual object we are going to shoot. is the transmission map, also called depth map, showing the depth of field of observation (give Chinese name). is a parameter called global atmospheric light.

In this published paper in 2010, Doctor Kaiming He and his team performed an empirical and statistical investigation of the characteristic of haze-free outdoor images. They found that there are dark pixels whose intensity values are very close to zero for at least one color channel within an image patch. Based on this observation, a dark channel is defined as follows: , where is an intensity for one of an RGB color channel and is a local patch centered at pixel x. From 5000 dark channels of outdoor haze-free images, it was found that most of the pixels in the dark channels have 0 values. . This approximation is called DCP. On the contrary, the dark channels from hazy images produce pixels that have values far above zero, which implies that the pixel values of the dark channel can serve as an important clue to estimate the haze density.

If you still remember the degradation model mentioned in the previous slides, the goal of dehazing is actually to achieve from , and , so we can do a simple mathematical transformation to get this equation. is what we have right now, so the rest of things we need to do is to get and . It all begins with the construction of the dark channel of . The construction of dark channel image is based on one equation mentioned in last slide. You can see it as a minimum filter imposed on every patch. There are two ways to implement this minimum filter in code, one is the conventional for loop method we have used a lot in our course lab. The other one is a fast algorithm proposed by Marcel van Herk.

After having dark channel image, we can estimate atmospheric light A from it. One method of estimation is to choose the intensity of the pixel with the highest dark channel value as the value of atmospheric light A. . Another method is to choose the intensity of the pixels with a top p% dark channel values as the value of atmospheric light A. Two typical values of p are 0.1 and 0.2. A third method is to use local entropy . The pixel with the lowest entropy value is used to obtain A among the highest p% pixels in the dark channel.

The transmission map, also called depth map, can be estimated as , which can also be derived from degradation model and DCP. The parameter is introduced intentionally to maintain a certain degree of haze in dehazed image to preserve the sense of depth field, since haze is an important source of depth of field. Its value is from 0 to 1.

If we use the estimated transmission map directly to construct the haze free result image, then the result would be like this. Although the haze is largely removed, the block artifacts are obvious. Therefore, we need to refine the transmission map. The method mentioned in the original paper in 2010 is to use soft matting. But this method consumes a huge amount of computer memory making it impractical for large size image, so I will not implement this method in my program. In one of his later papers, Doctor Kaiming He proposed a way to replace soft matting called guided filtering. (The essence of guided filtering is to use the original hazy image as a guidance to help to sharp and refine the shape of the transmission map.) After guided filtering, the refined transmission map is shown here. Compared with the unrefined one, the refined transmission map has the basic shape and the sense of depth of field of the original image.

The constructed haze free image is shown here. And several other examples are also shown. We can see from these results that the dehazing algorithm successfully accomplish its task – most of the haze is removed and some of the haze is maintained intentionally to preserve the depth of field.

So finally, we come to the performance analyses part. As I mentioned, different papers proposed different methods to accomplish the same task, so I want to summarize and compare these methods and give an instruction of the choices of parameters. In most of the time, the evaluation of a digital image processing technique is based on human eyes, which is fairly subjective. Luckily, I found a database called FRIDA. The database contains images without fog and 72 hazy images in three types (– homogeneous fog, heterogeneous fog, cloudy homogeneous fog and cloudy heterogeneous fog.) It also contains the depth map / transmission map of the images without fog. Therefore, we can use the images without fog and their depth map as ground-truth for evaluation. Since the dehazed image is highly dependent of the refined transmission map, so I put the 72 hazy images in FRIDA into my program, get their refined transmission map, and calculate the average root mean square error between the refined transmission map in my dehazing program with the depth map / transmission map of the images without fog in FRIDA to evaluate the performance qualitatively.

As I mentioned before, there are two methods to do the dark channel construction. One is a fast algorithm proposed by van Herk. This graph shows the time consumption of all four steps in our dehazing algorithm for different dark channel patch size. Bars in different colors represent different four steps. The horizontal axis is time and the vertical axis is patch sizes. As we can see from this graph, the time to do dark channel construction increases a little bit as the patch size increases. But the time is very short, around 0.2 s. The dominant time consumption in the whole process is guided filtering.

However, if we use the conventional patch based for loop method, the time consumed in dark channel construction increases dramatically from around 0.2 s to around 2 s. Since the time consumptions in other steps do not change a lot, the time for constructing dark channel dominates the whole process. This shows the advantage of van Herk’s algorithm over conventional for loop method. (Also, as the same with the previous graph, the time to do dark channel construction increases a little bit as the patch size increases. This is quite reasonable, because as the patch size increases, the number of elements need to be compared in each patch increases, thus increasing the workload of the computer and thus increasing the time.)

As we have mentioned before, the total time consumption in the whole dehazing process is significantly larger in conventional for loop method than in van Herk’s algorithm.

As for the average RMSE, which is a criterion for judging the quality of dehazing, for both methods in constructing dark channel, the RMSE increases as patch size increases. This phenomenon can be explained by that as the patch size gets too large, some tiny or fine textures would be lost in some patches. Therefore, a small patch size that does not produce false textures in dark channel needs to be found.

For atmospheric light estimation step, as I mentioned there are four methods to do this estimation. The vertical axis is the four methods, the horizontal axis is the time consumption. Bars in different colors represent different four steps in the whole dehazing process. As we can see from this graph, the method in atmospheric light estimation does not affect the time in other steps. For the time in atmospheric light estimation itself, the entropy method consumes much more time than the other methods.

For the average RMSE in atmospheric light estimation, as the patch size increases, the three methods besides entropy method yields decreasing RMSE, which shows that the quality increases as the patch size increases. This is contradictory to the patch size in dark channel construction, which recommends the patch size to be smaller. The practical solution to this contradiction is to use two different patch sizes for these two steps. In dark channel, set it smaller, and in atmospheric light, set it larger. The advantage brought by the time-consuming entropy method is its constant RMSE regardless of patch size. So, if you do not want to change the patch size for different steps, and do not care about the time, then entropy method is a good choice.