Analysis of Guided Filters in Image Processing Evidence from Feathered Mask

Shengting Jiang*

Department of Physics and Astronomy, University College London, London, United Kingdom

* Corresponding Author Email: shengting.jiang.21@ucl.ac.uk

Abstract. As a matter of fact, with the development of the electronic computers, the technique of fast Fourier transform is used in the realm of image processing. In reality, when dealing with different situations, a variety of filters and kernels will be applied and the guided filter is one of these. With this in mind, in this study, the specific task of feathered mask of image processing will be analyzed. According to the analysis, the filters improve the details at the edge of the image mask. It shows that the guided filters perform well on edge preservation and image enhancement. Moreover, the limitations and improvement will also be raised in the article at the same time. This paper aims to raise the interest of the guided filters in the realm of image processing and give some future outlooks of this method. Overall, these results shed light on guiding further exploration of Feathered musk.

Keywords: Image processing; fast Fourier transform; guided filters; feathered mask.

1. Introduction

The concept of Fourier Series was raised by Joseph Fourier in 1822, which states the property that any continuous or discontinuous function can be converted into a sum of sinusoidal functions. The process of converting a function to its sinusoidal sum refers to the Fourier transform [1]. Since light and image information can be expressed as a set of data or a function, Fourier transform also plays important role in optics analysis [2]. Fast Fourier transform is a technique based on the Discrete Fourier transform which gives a general and rapid method to deal with discrete data. The method of FFT divides every step of transform into two pieces of transform with half data size [3]. The reduction in complexity makes FFT the most widely used form of Fourier transform in optics application.

In the very beginning of the development of Fourier optics, the theory was deduced from basic theory of light. Such as scalar diffraction theory is part of Fourier optics [4]. With the development of electronic computer in early 20th century, more significant topics in Fourier optics were raised [5]. One of the most important research projects is the holographic method which based on the pioneering work on soft X-ray microscopy [6]. Electronic computers play a very important role in modern science research, digital Fourier optics shows great potential on image processing. A digital image on computer can be processed as a set of discrete data. When applying Fourier transform on the image data, the data can be converted into frequency-domain which allows us to apply filter which pick out or advance certain frequency. Denoising is also another application in digital Fourier optics [7]. Electronics dominate experiments and engineering production today and will be more significant in the future. This refers to image processing on more complicated image with noise and useless information. It is quite essential for the world to develop more efficient way of image processing and make comparison on different methods and filters under certain circumstances.

The effort on improving application of fast Fourier transform on digital image processing never stops. As mentioned above, the basic concept of digital Fourier transform is to convert discrete image data from its original domain into frequency domain which gives us a way to apply filters on the data to filter out certain frequency and noise. This implies many methods which are suitable for certain situations. In the case of image processing, the quality of a wide range of images, including medical imaging, microscopy and remote sensing images will be improved using image processing technique like enhancement because their accuracy is doubted by issue with visibility, contrast and noise etc. [8, 9]. The method used in image processing are mainly based on a variety of filters. One of the most popular types of filters, linear filters operate data linearly into the frequency domain and apply a

kernel coefficient to the transformed data. This category includes Gaussian filter, Sobel filter, and Guided filter. Gaussian filter is frequently used to denoise high-frequency noise to blurring and smoothing images, Sobel filter is used for edge detection, and Guided filter is mostly used for picture enhancement [9-12].

Convolutional Neural Networks (CNNs) which based on the machine learning is one of the most edge-cutting technique in image processing realm. When using this method, each neuron learns a feature engineering via filter optimization and will be able to extract data into smaller pieces of information [13]. In image processing, this technique maps data into the frequency domain. When used for medical image analysis, image and video filtering, and enhancement, CNNs offer significant benefits [14-16].

In the realm of image processing, the quest for achieving optimal results in tasks such as denoising, enhancement and edge preservation smoothing with as much details information as possible remains an enduring challenge. Although existing linear filters have come a long way, they frequently struggle with striking the delicate balance between blurring images to reduce noise and keeping important details that support image integrity. Guided filters emerge as a potent instrument with quick processing time and effective enhancing outcomes [17]. When compared to Gaussian and Sobel linear filters, the guided filter has a distinct advantage. High-frequency noise can be perfectly removed with the use of the Gaussian approach but also losing some of the image's detail information [10]. The Soble filter, which is used in edge detection frequently, is unable to handle noise properly [11].

Guided filters, with their ability to dealing with local image data with great balance between applications, are better choice in linear operators. In essence, guided filters offer a precise way that adapts operations to unique characteristics of each image, serving as the definitive representation of the delicate balance sought in image processing.

This paper will make a discussion and comparison on a certain aspect of guided filters on image enhancement. It aims to prove not only the strength of the method but also the limitations. In subsequent sections, the model and method of guided filters will be introduced with principles. Then the result of image processing which specifies feathering mask using the technique will be displayed and compared with the original data. With the help of comparison, the result and conclusion will be accessed properly at the end of this article.



Fig. 1 The original image cited from Kaggle. Presenting a pigeon with a lot of feathers.

2. Data and Method

In this paper, only one image will be processed using guided filters. The image was cited from the database created by Akash Kumar on Kaggle (seen from Fig. 1) [18]. In order to save storage and compress information of image in electronic computer, the information especially at the edge of object will be largely lost. The technique of image masking is used to approximately get a silhouette of the object from the original image. Meanwhile, the size and the information of this image will be

largely reduced. As a result, the details of the shape will be affected with lots of lines and corners. Guided filters can make the edge smoother with feathering mask technique [19].

In this part, principles of guided filters will be introduced with formulae. First of all, since guided filters are linear operators, a general definition of linear translation filtering process can be deduced by a guidance image I, an input image p and the output image q. The output image data q_i at pixel index i can be expressed as a weighted linear relationship by input image data p:

$$q_i = \sum_j W(I)p_j \tag{1}$$

Where $\sum_j W$is a function related to the guidance image I and independent to the input image p, i and j are pixel index representing the position of the image data. Then, the kernel needs to be defined. The most important assumption of the guided filter is that the filters is totally linear model between the guidance image I and the output data q. Assuming that q is a linear transform of I centered at the pixel k of the image:

$$q_i = a_k I_i + b_k, \forall i \in \omega_k \tag{2}$$

Where ω_k represents the area at the center of the image within k pixels, a_k and b_k is a set of linear coefficient that is assumed to be constant in the area ω_k. Eq. (2) ensures that q_i is one-to-one corresponding to the guidance image I_i and q has edge only if I has one. This gives a idea that if one wishes to do the feathering mask of a image, it would be better to use the identical image as the guidance image. In order to determine the linear coefficient a_k and b_k, the solution to Eq. (2) that minimizes the difference between output image q and input image p can be obtained as [19]:

$$E(a_k, b_k) = \sum_{i\in\omega_k}((a_k I_i + b_k - p_i)^2 + \epsilon a_k^2) \tag{3}$$

Where ϵ is the regularization parameter that prevents the coefficient a_k from being too large. Additionally, ϵ usually gives a value between 0.1^2 to 0.4^2. The solution to (3) can be obtained by linear regression [20]:

$$a_k = \frac{\frac{1}{|\omega|}\sum_{i\in\omega_k} I_i p_i - \mu_k \overline{p_k}}{\sigma_k^2 + \epsilon} \tag{4}$$

$$b_k = \overline{p_k} - a_k \mu_k \tag{5}$$

Where μ_k and σ_k^2 are the mean and variance of I under the constraint ω_k, ω is the total number of pixels inside the area ω_k and $\overline{p_k}$ is the mean value of p inside ω_k. Now, one applies the result to the whole image. The model will be expended into the whole graph instead of only the central area ω_k. However, the value of q_i involves all areas ω_k that contains i, so the result from Eq. (2) will be corrected by taking average of all possible values of q_i. With the result from Eq. (3) and Eq. (4) according to all values of ω_k. One can adjust the presentation of the q_i:

$$q_i = \frac{1}{|\omega|}\sum_{k:i\in\omega_k}(a_k I_i + b_k) = \overline{a_i} I_i + \overline{b_i} \tag{6}$$

Where $\overline{a_i} = \frac{1}{|\omega|}\sum_{k\in\omega_i} a_k$ and $\overline{b_i} = \frac{1}{|\omega|}\sum_{k\in\omega_i} b_k$.

Another important change due to the modification is that the q is not linear transformation of I anymore, because the linear coefficient a_i and b_i vary. For the same reason, Δq is not scaling of ΔI which means the edge of the image may be influenced. But since a_i and b_i are the average value of the different coefficients, the change of these coefficient is weaker than the change of guidance image I when it approaches rapid change such as strong edge. This refers to the result that one can still consider $\Delta p \approx \bar{a} I$, which means that most of the intensity change in I can be applied to q well. The relationship among I, p and q is given by Eqs. (4)-(6). Next step is to rearrange the filter into the form of (1). a_k and b_k in Eq. (4) and Eq. (5) can be expressing in the form of weighted sum of p. Then the total weight in (1) can be obtained [19]:

$$W_{i,j} = \frac{1}{|\omega|^2}\sum_{k:(i,j)\in\omega_k}\left(1 + \frac{(I_i-\mu_k)(I_j-\mu_k)}{\sigma_k^2+\epsilon}\right) \quad (7)$$

and the expression is already normalized.

3. Results and Discussion

Since one is dealing with the image masking research, the edge should be restricted by the guidance image I in order that the output image can have a clear edge. Thus, it would be better choosing the gray version of an identical image as the guidance image. In this case, every pixel of input image p is one-to-one corresponding to the guidance image I, so the change in intensity will be enhanced in the process while the edge of the image will also be preserved and enhanced. In order to process the figure feathered mask, the mask of original image will be produced by filtering out the background. The input image will be processed by certain channels and the background information will be filtered. The technique is based on the binary mask method and the edge of the object will be highlighted, as shown in Fig. 2 [21, 22].



Fig. 2 The outcome of image masking of the original image. The edge of the mask is consist of lots of lines and corners with little amount of details.



Fig. 3 The feathered mask of original image with regularization parameter $\epsilon = 0.1^2$. Mask image with small size and better details on the edge of the bird.



Fig. 4 The zoom of the original mask image, it shows continuous line and corner.

The guided filter will be applied on the original mask image in order to enhance the details on the edge (feathered mask). As mentioned above, the output image data can be approximately considered as a linear transformation of the guidance image I. The intensity change in I will be reacted to the outcomes, so the intensity change at the edge will be able to enhance the details and information on the mask. The feather of the bird can be seen on the result. Compared to the original mask, it is obvious that the edge of the feathered mask has more information and greater accuracy. This implies that the guided filter can effectively improve the texture of picture. When one looks closer at the results (seen from Fig. 4 and Fig. 5).

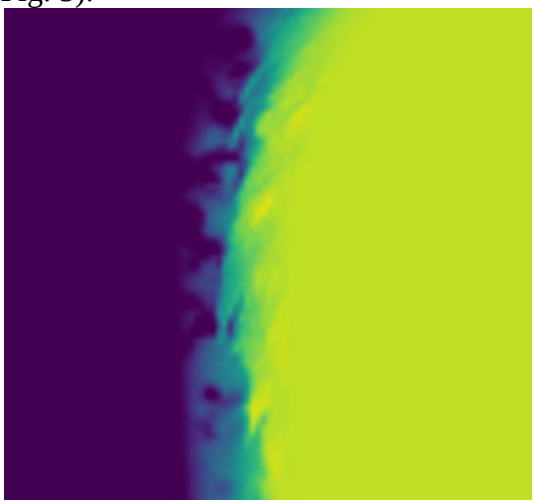


Fig. 5 The zoom of the feathered mask image, it shows the frequent change in the slop which refers to more details and information.

With the comparison of the zoom of original and feathered mask image, the change of the gradient at the edge of the feathered mask is much more frequently and stronger than the original mask. It refers to the improvement of the guidance image provide. There is a halo around the edge of feathered mask image. This is caused by the noise and the error at the change in intensity of guidance image at the area. When the accuracy of the guidance image increases, the corresponding output data will also gain greater accuracy. This is because the pixel change on the guidance image results in the change on the output image. Another way to improve the accuracy is to decrease the regularization parameter ϵ, smaller ϵ means smaller tolerance for the linear coefficient which results in the better accuracy. When looking at these images, it would be easy to say that guided filters are powerful and potential tool in image processing. It can enhance most of the details of the image and remove noise. In the realm of image masking process, the edge information is enhanced as much as possible and this will make great advantage in science realm.

4. Limitations and Prospects

The guided filters method's reliance on the guidance image is one of the key limitations. Although it is possible to utilize the image itself as the reference image, the output image's performance is strongly related to the original image's quality, so if the original image is noisy or inaccurate, the outcome will not be satisfactory. For the same reason, it is not suitable for the guided filters to deal with extreme noise. The guided filters, just like other types of explicit filter shares a common drawback. The halo around the edge cannot be eliminated efficiently and this may cause trouble in the output [19]. The guided filters have great performance on denoising and details enhancement, but it may not be suitable for all kinds of application such as filtering out certain frequency data in the image.

Since the guided filters is a linear operators, it can be regard as a simple case of learning. It can be obtained in other advanced models. Another possible improvement is the application in the machine learning. The guided filters can be included in the convolutional neural networks (CNNS) as a learning features. With the development of machine learning and artificial Intelligence, the

combination of multiple filters and kernels can be done more easily by the edge-cutting techniques. Another improvement can be made in the guided filters is that it is necessary to develop a faster version of the filters. The main concept of the improvement is to save time for processing complicated images and this may be achieved by selecting useless information out of the processing [23]. With faster processing speed, the efficiency will be largely improved. As the guided filter is a kernel that can only deal with photographic image processing, there might be able to develop a new version of the filter that can deal with other type of information such as spectrum and voice.

5. Conclusion

To sum up, this study discusses the guided filters in the image processing realm in the work of feathered mask. The guided filters as a linear operators show a powerful performance on the edge preservation in the process. With the help of the guided filters, one can get a much clearer edge for the image mask although there is still a halo around it due to the common limitation of explicit filters. In conclusion, the performance of the guided filters is satisfactory with only few errors around the edge. Nevertheless, it also shows a limit of the high dependence on the guidance image. In addition, it is easy to predict that the guided filters have great performance on denoising and image enhancement but poor at other image processing applications. It might be better to combine the filters with other techniques such as CNNs. This paper shows the potential of the guided filters and review the possibility of the application on the mask enhancement.

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