Application of Image Restoration in On-Line Detection of Optical Element Damage

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Abstract. With the continuous development of technology, Image processing methods based on computer vision began to shine in the field of image processing. There are many easily damaged optical equipment, traditional off-line detection technology requires analysis of components in optical devices after disassembly. Therefore, offline detection technology cannot guarantee the efficiency of the device, It also affects the cost and life of the equipment. Therefore, the research on the online detection technology of optical component damage has become an urgent problem to be solved. In this paper, an online damage detection method for optical elements based on image restoration is proposed. Then, the whole image and block image are processed by this method to verify the processing effect.

1. Introduction

In this paper, the image is modeled by the degradation model restoration technology. Then, based on the prior knowledge in the damage image, the restoration algorithm is designed for the damage image. And the algorithm is applied to the restoration of the degradation model of the damaged image. Finally, the experimental results are observed and compared with the traditional image processing methods at home and abroad.

Degradation model restoration technique[1] is used to improve image quality by restoring images. Digital image restoration technology is a computational process of image restoration based on backward reasoning.

In the traditional image restoration technology, the main methods used are inverse filtering, wiener filtering, bayesian image restoration, geometric mean filtering and so on. The inverse filtering requires accurate estimation of the degenerate function \( H(u,v) \), then we use the estimated degradation function to restore the image. But in practice, images that need to be processed are often accompanied by a variety of complex noises. Therefore, the inverse filtering method has great limitations in practical application.

\[
\hat{F}(u,v) = \frac{G(u,v) + N(u,v)}{H(u,v)}
\]

As shown in the above formula, even though we know exactly what \( H(u,v) \) is. However, in practical application, since we cannot know \( N(u,v) \), we still cannot recover accurately.
2. A priori knowledge of damage images

All the image data used in this paper are obtained from target imaging after the damage of optical components. There are many optical components in optical devices. Due to the large number of optical components in large optical devices and the large number of optical systems. Therefore, the imaging environment is extremely complex, and there are various noises, and it is impossible to make a completely reasonable prediction of these noises.

Since the damage of optical components is a self-accelerating process. Therefore, the damage effect, damage shape, damage property, etc. will also change with time, and the degradation process cannot be accurately obtained, nor can it be accurately modeled to estimate the degradation function. Therefore, the results and models obtained by the algorithm used in this paper are all approximate values and approximate estimation models.

Through the analysis of the damage process of optical components, it can be found that during the operation of large optical devices, the laser generated may cause certain damage to the inner wall of components, resulting in the thermal melting and even melting effect. In this case, laser irradiation on the inner wall may produce a large amount of smoke, resulting in the loss of image contrast, image boundary, image contour and other information. In addition, in the imaging process of damage images, there are many factors that affect the imaging environment, such as dust on the surface of imaging equipment, water mist or impurity light generated by other injuries, and scattering of optical components. All these factors may cause the image quality of optical component damage imaging to decrease, and the light intensity in the image is uneven and the grayscale value is changed.

![Figure 2 Background area and damage area](image)

As can be seen from Figure 2, no matter the damaged area or the background area, there will be problems such as reduced contrast, unclear area boundary and unclear image details[2-5]. Through the above analysis, the degradation process of the damage image of optical components is similar to that of the image affected by smoke, water vapor, dust and other interference factors. Therefore, this paper will compare the image degradation process in the degraded image affected by smoke, water vapor, dust and other interference factors, and simulate the degradation process of optical component damage image by using atmospheric scattering, atmospheric light imaging and other degradation processes.

3. Restoration algorithm for optical components
As mentioned above, the image of damage collected in this paper has a complicated imaging environment with various random noises and complex and variable damage effects. Therefore, the degradation process cannot be accurately obtained, nor can it be accurately modeled, so the degradation model adopted in this paper is an approximate model. Through analysis, it is found that the damaged image will be affected by dust particles and water vapor around the mirror, resulting in attenuation of light energy, uneven change of light intensity and change of image gray value. In addition, the damage may be accompanied by a thermal melting effect that produces a large amount of smoke, which may also lead to reduced contrast in the damaged area, blurred boundaries, and inconspicuous image details. Through analysis, it is found that the degradation process is very similar to that of fog images. Therefore, this paper will adopt the model of the influence of severe weather conditions such as haze weather on the image. In this paper, the atmospheric scattering model and the attenuation model of the atmospheric light imaging process are used to approximate the degradation process of the damage image. Its model expression is as follows:

\[
L(x, y) = L_s(x, y)e^{-kd(x,y)} + L_0(1 - e^{-kd(x,y)})
\]

In the above formula, \(L(x,y)\) is the image polluted by noise, \(L_0(x,y)\) is the image to be restored, \(K\) represents the atmospheric scattering coefficient, \(d\) is the depth of the image. \(L_s\) is for panoramic atmospheric light. It's usually constant. There are many methods to recover degraded images based on the above model. These also achieved good results[6-9]. Combined with the real-time requirement of online damage detection in this paper. In this paper, based on reference [8], only through mean filtering, the estimation method of degradation parameters and noise is given to realize fast image restoration. The basic principle of the algorithm is as follows: The algorithm replaces \(L_s(1 - e^{-kd(x,y)})\) with \(V(x,y)\), then the formula above can be changed to:

\[
L(x, y) = R(x, y)(1 - \frac{V(x,y)}{L_s}) + V(x, y)
\]

The mean filter is used to approximate the environmental light \(V(x,y)\) and global atmospheric light \(L_s\). The estimated form is as follows:

\[
V(x,y) = \min(\min(\alpha m_{ave}, 0.75)L_{average}(x,y), L(x,y))
\]

\[
L_s = \frac{1}{2}(\max(L(x,y)) + \max(L_{average}(x,y)))
\]

In the above formula, \(L_{average}(x,y)\) represents the result of a mean filtering operation on the input image, \(m_{ave}\) is the mean value of the global image, \(\alpha\) is the adjustment parameter and \(0 \leq \alpha \leq 1 / m_{ave}\).

Finally we can figure out:

\[
R(x,y) = \frac{L_s(L(x,y) - V(x,y))}{L_s - V(x,y)}
\]

4. Results
In order to verify whether the algorithm proposed in this paper can effectively restore the images collected in the experiment and obtain a better result graph. This paper will be compared with median filtering. The experimental objects were all images of optical component damage. In the following figure, damage images of optical components are processed by different methods. As can be seen from the result graph, the damage image of optical components restored based on the algorithm in this paper has no significant impact on the image details while denoising. Therefore, this algorithm can better preserve the image details.

As shown in Figure 3 below, sub-figure a is the original damage image, and sub-figure b-e is the result after being processed by several processing methods commonly used in the field of damage image
processing[10-13]. It can be seen that these methods are not suitable for the image with complex noise that needs to be processed in this paper.

![Image with Gaussian noise added](image1.png)

![Mean filtering performed on figure a](image2.png)

![Median filtering performed on figure a](image3.png)

![Morphological filtering was performed on figure a](image4.png)

![Image enhancement performed on figure a](image5.png)

**Figure 3** The damage image is processed according to the traditional image processing method.

Compared to previous studies[11, 14], the image processed by the algorithm in this paper is processed by threshold segmentation to obtain image e. The method in this paper is compared with the previous methods of edge detection and median filtering. In this paper, the damage point details of the damage image are clearly screened, and the part of the suspected damage point is also properly handled, but not all of them are discarded or retained.

![After median filtering](image6.png)

![After algorithm processing in this paper](image7.png)

**Figure 4** The original image processing algorithm is applied to the damage image as a whole compared with the algorithm in this paper.
It can be seen from Figure 3 and Figure 4 that median filtering has little effect on image quality improvement. The image edge detection technology can find the damage point after setting the relevant threshold. However, edge detection does not have a good effect on the identification of other suspected damage points. The original structure of the image processed by the algorithm in this paper is still clear, and the image quality has been significantly improved. After threshold segmentation, damage information can be clearly presented on the image.

![Image](https://via.placeholder.com/150)

Figure 5 The edge detection algorithm is used to compare the image of damage area with the algorithm in this paper.

The image block of damaged area is processed by this method, and the result is compared with that of edge detection. It can be seen from the figure above that the algorithm proposed in this paper is superior to the traditional edge detection method in both light and dark field imaging in the online processing of damage images.

5. Conclusion
This paper mainly introduces the basic knowledge of the degradation model restoration technology and the implementation details of the degradation model restoration algorithm used in this paper. Image restoration algorithms are essentially a way to improve the visual quality of images. In this paper, the specific improvement process and application model of the restoration algorithm of the degradation model used are described in detail. Then, this paper carries out comparative experiments, and compares the image processing effect with median filtering and edge detection technology in terms of whole and block, low and high noise, and further illustrates the effect of this algorithm in the damage image detection of optical components. Experimental results show that compared with the traditional filtering operation and edge detection method, the method used in this paper has a better effect in the online detection of optical component damage images.

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