Differential filtering algorithm for robot welding seam image enhancement

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Abstract. The low resolution of the welding seam recognition image during robot welding will affect the welding accuracy, and the cost of high-resolution cameras is higher. Therefore, in this paper, the geometrical processing of the bilinear interpolation method for the welded seam pictures taken by the low-resolution camera was used to obtain a high-resolution image. This paper proposed a differential filtering algorithm based on Gaussian filtering and bilateral filtering, to eliminate the fine lines, noise and enhance the weld feature value for the obtained high-resolution image, thereby ensuring the welding accuracy. Finally, through the image processing experiment of increasing the 1.25 million pixel weld image to 5 million pixel weld accuracy, the effectiveness of the image enhancement method proposed in this paper was proved.

1. Introduction

With the rapid development of modern industry, the adoption of robot welding is a necessary change in the field of industrial manufacturing to serve various processing enterprises. At present, factories use the teaching-playback robots commonly, which means that people give the motion trajectory of the (teaching) robot in advance. Then the robot accurately repeats the path [1]. However, for the welding of non-standard parts, such as the automobile parts manufacturing industry, there is no unified standard for automotive welding parts, so there will be some deviation in size. Besides, many small and medium-sized machining enterprises do not require precision and surface roughness for the machined products themselves, and the position of the weld seam often changes. Therefore, we usually mount a vision sensor on the robot arm to accurately find the location of the welding seam to achieve the purpose of automatic welding [2], that is, automated welding based on machine vision [3].

The field of automatic robotic welding uses machine vision widely [4]. But for most small and medium-sized enterprises, they need high-resolution industrial cameras to achieve welding accuracy. Due to the high cost and difficulty in procurement, the demand for welding image enhancement technology is getting higher and higher. Such as in the manufacturing industry of marine anchor chains, there is no requirement for the processing accuracy of anchor chains, and there is no need to carry out grinding and polishing. When the robot welds the anchor chain rung, the image captured by the camera has noise and fine lines, which results in the weld seam characteristic value not being apparent. Therefore, how to achieve the same accuracy of welding seam recognition with a low-pixel camera as with a high-pixel camera requires image enhancement processing before finding the welding seam.
Based on the above background, this paper first adopts geometric transformation for low-resolution weld seam images to obtain high-resolution weld seam images. On this basis, the paper proposes a differential filtering algorithm based on Gaussian filtering and bilateral filtering, which can not only eliminate the fine lines and noise of the resulting high-resolution weld image but also enhance the edge characteristics of the weld image. Furthermore, an image processing experiment with a 1.25-megapixel weld seam image taken by a low-resolution camera to achieve a 5-megapixel weld seam accuracy proves the effectiveness of the proposed seam image enhancement method proposed in this paper.

2. Geometric processing of weld image

In order to obtain a high-resolution weld image, the geometric model of the weld image is transformed firstly during preprocessing. Image interpolation technique is the conventional methods in geometric transformation [5]. This paper takes the robot welding of anchor chain rung shown in Figure 1 as an example to study the welding image interpolation technology.

For the original image of the anchor chain weld seam taken by a 1.25-megapixel camera shown in Figure 2, the pixel is increased to 5 million for interpolation. At present, there are three main standard interpolation methods, which are the nearest neighbour interpolation method [6], bilinear interpolation method [7] and bicubic interpolation method [8].

In the nearest-neighbor interpolation, the gray value of the pixel is simply rounded when selecting the pixel to be inserted, so there is a phenomenon of gray discontinuity, and other adjacent points are not considered, resulting in the interpolated image jaggedness will appear at the edges, and there will be mosaic phenomenon after the image is enlarged.

Bilinear interpolation solves the problem of jagged edges in the nearest neighbour interpolation [9]. However, its low-pass filtering characteristic suppresses high-frequency signals, so the phenomenon of blur appears at the edge of the image.

Compared with the other two methods, the edge of the image processed by the bicubic interpolation method is the clearest. But the interpolation takes several times or even dozens of times as long as other ways, which makes it difficult to realize real-time processing of image signals for welding operations.
According to the trade-off between the sharpness of the processed image and the processing time, we choose the bilinear interpolation for subsequent research. The detailed image of the weld after bilinear interpolation is shown in Figure 3.

3. Weld image enhancement based on differential filtering

Image filtering is to suppress the noise that affects the subsequent operations while ensuring the details of the original image \[10\]. In this paper, after the bilinear interpolation, the resolution of the weld image becomes four times larger. Still, the edge of the weld also becomes smooth, which makes the weld image blurred. Therefore, it is necessary to perform the corresponding filtering to sharpen the weld edge \[11\] and at the same time, reduce the noise in the image.

The processing method of weld edge sharpening is generally to extract high-frequency components by high-pass filtering \[12\] to enhance the contour of the weld edge and the part with large greyscale change. The side of the weld is brighter than before after sharpening, but the noise in the detail part is also more prominent. Therefore, the operation method of direct sharpening cannot be adopted.

The bilateral filtering plays a role of edge preservation and denoising \[13\]. The method is to multiply and sum the weights of the Gaussian kernel template in the spatial domain and the pixel range domain and then normalize it \[14\]. This method helps to remove the noise of useless details while retaining the edge information of the image \[15\]. However, in bilateral filtering, if the weight of the Gaussian kernel module in the spatial domain reduces, the noise reduction effect can be achieved, but the importance of the Gaussian kernel module in the pixel range domain will decrease accordingly, and the impact of edge sharpening will be unsatisfactory, and vice versa. So the bilateral filtering is difficult to achieve the ideal state of edge sharpening and noise reduction at the same time.

Therefore, this paper proposes a differential filtering method based on Gaussian filtering and bilateral filtering to achieve sharpening of the weld edge while denoising. The specific operation is as follows.

Firstly, we apply Gaussian filtering to the weld image. For the Gaussian kernel module window of a certain $n \times n$ pixel, it traverses the image and multiplies it with the image pixels. The specific algorithm is shown below.

$$G_\sigma = \frac{1}{2\pi\sigma^2} e^{-\frac{(x-x_c)^2+(y-y_c)^2}{2\sigma^2}} \quad (1)$$

In equation (1), $G_\sigma$ is a Gaussian kernel function, $(x_i, y_i)$ is a point in the neighbourhood, $i \in n$. $(x_c, y_c)$ is the centre point, and $\sigma$ is the standard deviation.

The pixel value $I_{p1}$ of the output image after Gaussian filtering can be obtained according to the following formula.

$$I_{p1} = I \ast G_\sigma = I \frac{1}{2\pi\sigma^2} e^{-\frac{(x-x_c)^2+(y-y_c)^2}{2\sigma^2}} \quad (2)$$

In the formula, $I$ is the pixel value of the input image.

Next, bilateral filtering is performed on the weld image, and the specific algorithm is shown below.

$$G_s = e^{-\frac{(x-x_c)^2+(y-y_c)^2}{2\sigma_s^2}} \quad (3)$$

In equation (3), $G_s$ is a Gaussian function in the spatial domain, $(x_i, y_i)$ is a point in the neighbourhood, $i \in n$. $(x_c, y_c)$ is the centre point, and $\sigma_s$ is the standard deviation of the spatial domain.

$$G_r = e^{-\frac{(g(x,y)-g(x_c,y_c))^2}{2\sigma_r^2}} \quad (4)$$

In equation (4), $G_r$ is the Gaussian function in the pixel range domain, $g(x_i, y_i)$ is the gray value of a point in the neighbourhood, $g(x_c, y_c)$ is the gray value of the center point, and $\sigma_r$ is the standard deviation of the range.

The weight function $W$ of the pixel value in each filter window can be obtained according to the following formula.

$$W = G_s G_r = e^{u} \quad (5)$$
\[ u = -\frac{(x_i - x_c)^2 + (y_i - y_c)^2}{2\sigma_s^2} - \frac{(g(x_i, y_i) - g(x_c, y_c))^2}{2\sigma_r^2} \]

The pixel value \( I_{p_2} \) of the bilaterally filtered output image can be obtained according to the following formula.

\[ I_{p_2} = \frac{\sum_{i=1}^{n} G_s G_r I}{\sum_{i=1}^{n} W} \]

In equation (6), \( I \) is the pixel value of the input image. By adjusting the ratio of \( \sigma_r \) and \( \sigma_s \), the best effect of image edge preservation and denoising is achieved.

Then, to highlight the edge characteristics of the image, we need to extract the high-frequency components of the image in bilateral filtering. Therefore, the pixel value \( I_{p_2} \) after bilateral filtering and the pixel value \( I_{p_1} \) after Gaussian filtering are subjected to a differential operation to obtain the pixel value \( I_p \) as shown below.

\[ I_p = I_{p_2} - I_{p_1} = \frac{\sum_{i=1}^{n} G_s G_r I}{\sum_{i=1}^{n} W} - I G_\sigma \]

(7)

Finally, in order to emphasize the edge information of the image and at the same time achieve the purpose of noise reduction, the pixel value \( I_p \) of the high-frequency component obtained in equation (7) and the pixel value \( I_{p_2} \) after bilateral filtering are linearly added to obtain the final the pixel value \( I_p \) of the output image is as follows.

\[ I_p = I_{p_2} + I_p = 2I_{p_2} - I_{p_1} = \frac{2 \sum_{i=1}^{n} G_s G_r I}{\sum_{i=1}^{n} W} - I G_\sigma \]

(8)

4. Experimental results

This thesis takes the robot welding of the anchor chain rung shown in Figure 1 as an example and experiments with image enhancement processing based on differential filtering.

After bilinear interpolation of the 2.5 million pixel anchor chain image taken by the camera, we obtain a 5 million pixel image and call it the input image, as shown in Figure 4 (a). The output image after the image enhancement processing is performed on the input image is shown in Figure 4 (c) (b) (d) (e). Specific steps are as follows.

The first step is to perform Gaussian filtering on the input image. It is the weighted average value of each pixel in the image, traverse the image with a Gaussian template, and replace the gray value of the center point of the template with the weighted average of the pixels in the neighborhood determined by the template. The calculation of the pixel value is as shown in equation (2). Figure 4 (c) is the processed output image.

The second step is to perform bilateral filtering on the input image again. Using a bilateral filter to traverse the image, that is, the weighted average of the values in the neighborhood of all pixels in the filter window, increase the \( \sigma_s \) that controls the spatial proximity factor in the spatial domain to reduce noise, and decrease the \( \sigma_r \) that controls the brightness similarity factor in the pixel domain Highlight the edge of the anchor chain image. The ratio of \( \sigma_r \) to \( \sigma_s \) in this experiment is 4:1. After the bilateral filtering process, the calculation of its pixel value is shown in equation (6). Figure 4 (b) is the processed output image.

In the third step, the bilaterally filtered image and the Gaussian filtered image are differentially processed according to corresponding pixel values, and the pixel value of the high-frequency part of the anchor chain image is obtained as shown in equation (7). Figure 4 (d) is a high-frequency image.

In the fourth step, the high-frequency image obtained in the third step and the bilaterally filtered image are linearly mixed and added, as shown in equation (8). Figure 4 (e) is the final anchor chain image after image enhancement processing based on differential filtering.
Figure 4. Image Processing

As shown in the edge parts indicated by the dotted arrow in (e) and (c) of Figure 4, the comparison between the final image of Figure 4 (e) and the Gaussian filtered image of Figure 4 (c) shows that the welded edge of the Gaussian filtered anchor chain image is blurred. Still, the final image retains the high-frequency part of the input image, as shown in Figure 4 (d), and the welded edge is sharpened and more apparent.

As shown by the parts indicated by the four solid arrows in (e) and (b) of Figure 4, the comparison between the final image of Figure 4 (e) and the bilaterally filtered image of Figure 4 (b) shows that the noise of the bilaterally filtered anchor chain image is more apparent, and the noise of the final image is significantly reduced.

Finally, as shown by the parts indicated by the solid and dotted arrows in (e) and (a) of Figure 4, the input from the final image of Figure 4 (e) and the input image of Figure 4 (a) can be seen. The noise in the picture is obvious, the edge of the weld is not sharp enough, and it is not clear enough, while the noise of the final image is significantly reduced, and the edge of the weld is sharpened, and the weld is clearer.

Therefore, using the differential filtering algorithm based on Gaussian filtering and bilateral filtering proposed in this paper, a high-resolution weld image with significant weld edge characteristics and low noise is obtained, which is helpful for subsequent weld recognition.

5. Conclusion
In this paper, a differential filtering algorithm based on Gaussian filtering and bilateral filtering is proposed based on the low cost (low resolution) camera's welding seam image which can achieve the
same welding seam recognition accuracy as the high cost (high resolution) camera's image during the welding seam image processing process of robot welding.

The specific operation steps are as follows: firstly, the bilinear interpolation is adopted for the low-resolution weld seam image to obtain a high-resolution weld seam image. Then, a differential filtering algorithm based on Gaussian filtering and bilateral filtering is proposed, which can not only eliminate the fine lines and noise of the resulting high-resolution weld image but also enhance the edge characteristics of the weld image. Besides, an image processing experiment with a low-resolution camera taking a 1.25-megapixel weld image to achieve a 5-megapixel weld accuracy resulted in a high-resolution weld image with significant weld edge characteristics and low noise—the effectiveness of the weld image enhancement method proposed in the paper.

At present, this paper has carried out the demonstration of the image enhancement algorithm four times the magnification of the weld image. Subsequently, for the image processing of enlarging the image to higher pixels, it is necessary to carry out optimization research on the sharpening of high-frequency feature values for the case of severe loss of high-frequency features.

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