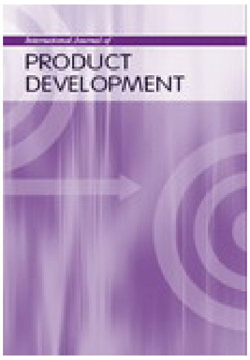

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Fuzzy edge detection method of product packaging image based on Kalman filter

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Abstract: The existing fuzzy edge detection methods for product packaging images are vulnerable to noise, resulting in the quality and effect of detection results cannot meet the actual needs, and the detection time is long, which affects the work efficiency. Therefore, based on Kalman filter algorithm, this paper studies the fuzzy edge detection method of product packaging image. Firstly, singular value decomposition algorithm is used to remove the noise of product packaging image. Then, the Fourier spectrum of the product packaging image is obtained by FFT operation, and the image blur parameters are quickly identified. Finally, the image fuzzy edge is processed by Kalman filter to realise image fuzzy edge detection. The experimental results show that the detection signal-to-noise ratio of the proposed method is as high as 61.5 dB, the quality factor is as high as 0.97, and the detection time is short, only 19.7 s. It can be proved that the proposed method can effectively improve the quality and efficiency of fuzzy edge detection of product packaging image.

Keywords: Kalman filter; singular value decomposition; FFT; product packaging image; fuzzy edge detection.

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1 Introduction

With the development of economy, while meeting people's material needs, people's spiritual needs are also improving. In addition to paying attention to product quality and commodity practicability, consumers also pay special attention to the outer packaging of products. The design of product packaging is directly related to the competitiveness of products in the market (Shan, 2021; Khuong and Tran, 2018; Cigula et al., 2021). At this stage of packaging design, computer technology and image technology are generally used to process and store the appearance information in product packaging design. The focus is how to realise the final product design through fuzzy edge detection of product packaging image. Image edge detection is an effective edge extraction of the target by using a special method to obtain the shape, size and direction of the target (Shi et al., 2020; Li et al., 2019). Feature extraction can be realised according to the edge pixel image.

At present, scholars in related fields have studied image fuzzy edge detection. Versaci and Morabito (2021) proposed an image edge detection method based on fuzzy entropy and fuzzy divergence. Using adaptive S-type fuzzy membership function, eddy current image, thermal infrared image and electrospinning image are blurred, the specific indexes of each image are quantified and the image edge detection is realised by formula processing according to the fuzzy divergence. Although the application of this method to image fuzzy edge detection can meet the needs of practical applications, due to the complexity of the calculation process, the detection time is long, which affects the detection efficiency. Feng et al. (2021) proposed an image edge detection algorithm based on fuzzy radial basis function neural network. The improved median filter is selected for denoising, the effect of image edge detection contour is used as Sobel operator for edge detection, the contour information of binary image edge detection is marked as the minimum outer rectangle, and the edge region of the target image is segmented to realise image edge detection. Although the algorithm can speed up image pre-processing and meet the requirements of real-time detection, it is vulnerable to noise in application, reducing the signal-to-noise ratio of the image, resulting in the detection quality and detection effect cannot meet the actual requirements.

In order to solve the above problems, a fuzzy edge detection method of product packaging image based on Kalman filter is proposed in this paper. The technical route of this article is as follows.

Step 1: the singular value decomposition algorithm is used to remove the noise in the product packaging image;

Step 2: get the Fourier spectrum of the product packaging image through FFT operation, and quickly identify the image blur parameters;

Step 3: the fuzzy edge of the image is processed by Kalman filter to realise the fuzzy edge detection of the image;

Step 4: through comparative experiments, it is verified that the fuzzy edge detection method of product packaging image proposed in this paper has the advantages of shorter detection time and higher detection quality, and can improve the efficiency of fuzzy edge detection of product packaging image.

2 Introduction to Kalman filter

Kalman filter is a method based on the state equation of the system by optimising the input and output of the system (Angeli et al., 2021; Padilla et al., 2020; Chen and Fu, 2021). Kalman filter can consider the influence of noise, interference and other factors, and can effectively denoise the data in need. It can estimate the state of the system according to a set of data with measurement noise. Kalman filter technology is a very practical filtering technology, which is widely used in communication, navigation, guidance, control and so on.

In the product packaging image, the grey value of adjacent pixels fluctuates near a certain average value due to coherence, resulting in coherent speckle noise around image pixels. Therefore, the fuzzy boundary detection of product packaging image will be affected by the difference between the distance and radial velocity of a large number of scattering objects, resulting in more scattering measurement in the product packaging image and affecting the effect of image edge detection.

Therefore, this paper applies Kalman filter technology to fuzzy edge detection of product packaging image, and combines image denoising technology to quickly identify image fuzzy parameters and realise fuzzy edge detection of product packaging image.

3 Fuzzy edge detection method of product packaging image

3.1 Remove image noise from product packaging

In order to effectively realise the fuzzy edge detection of product packaging images based on Kalman filtering, the singular value decomposition algorithm (Deeba et al., 2020; Zhang et al., 2021; Kousika and Premalatha, 2021) needs to be used first to remove the noise of product packaging images.

Assuming that $Q \in R^{Z_1 \times Z_2}\left(Z_1 \geq Z_2\right)$ is the image matrix of product packaging contaminated by noise, the rank $rank\left(Q\right) = r\left(r \leq Z_2\right)$ of Q, the singular value decomposition of corresponding Q is defined as:

$$Q = WEY^T \tag{1}$$

In formula (1), W and Y are left and right singular unitary matrices respectively, and $E \in R^{Z_1 \times Z_2}$ is a singular value matrix, T is the eigenvalue. According to the above definition, the zero singular value in Q is removed, then Q in formula (1) is simplified and expressed as:

$$Q = \sum_{i=1}^{U} \alpha_i E_i \tag{2}$$

In formula (2), α_i represents the diagonal element, U represents the rank of Q and E_i represents the i singular value of Q. The singular value of the image matrix is a reflection of the energy distribution of the image matrix. Usually, the energy corresponding to the noise is less, so it has less singularity. In this way, set a threshold as:

$$E_i \Big/ \sum_{i=1}^{U} \alpha_i \geq 90\% \tag{3}$$

The small singular values in the matrix are filtered and reconstructed with the remaining singular values to eliminate the noise of the product packaging image and reduce the impact of noise on the original image.

3.2 Fast recognition of fuzzy parameters of product outer packaging image

After the singular value decomposition algorithm is used to denoise the product outer packaging image, FFT operation is carried out for the product outer packaging image (Nishimura et al., 2021; Ferreira et al., 2021; Baszuro and Swacha, 2021), and the Fourier spectrum of the product outer packaging image can be quickly obtained:

$$P(z,x) = L(z,x)K(n,m) \tag{4}$$

In formula (4), z represents the original image of the product outer packaging, x represents the pixel points of the original image of the product outer packaging, $k(n,m)$ represents the degraded image of the product outer packaging, and $l(z,x)$ represents the Fourier transform of the expansion function of the original image. At the same time, within the exposure time β, the distances of the product outer packaging image at the horizontal and vertical angles are $c(\beta)$ and $v(\beta)$ respectively, dt represents the threshold of horizontal and vertical angles, then the original product outer packaging image can be expressed as:

$$k(n,m) = \int_0^{\beta} l\left(z - c(\beta), x - v(\beta)\right) dt \tag{5}$$

Combined with the nature of FFT transformation, fast FFT transformation is carried out on the original image of product outer packaging in formula (5), and the following formula can be obtained:

$$P(z,x) = L(z,x)\int_0^{\beta} e^{-j2\pi\left(zc(\beta)+xv(\beta)\right)} dt \tag{6}$$

Comparing formulas (4) and (6), we can get:

$$K(n,m) = \int_0^{\beta} e^{-j2\pi\left(zc(\beta)+xv(\beta)\right)} dt \tag{7}$$

Assuming that $J\cos\gamma$ and $J\sin\gamma$ correspond to the distance blur parameters of the product packaging image at horizontal and vertical angles, there are:

$$\begin{cases} c(\beta) = \beta \times J\cos\gamma \\ v(\beta) = \beta \times J\sin\gamma \end{cases} \tag{8}$$

Substituting formulas (8) into (9) can realise the rapid recognition of fuzzy parameters of product outer packaging image:

$$K(n,m) = \frac{\beta \sin \pi J \cos \gamma}{J \sin \gamma} \tag{9}$$

According to the above derivation and analysis, the identification of fuzzy parameters of product packaging images is completed.

3.3 Fuzzy edge detection of product packaging image based on Kalman filter

On the basis of the above-mentioned identification of fuzzy parameters of product outer packaging images, Kalman filtering is used to filter the fuzzy edges of the original image of product outer packaging, so as to realise fuzzy edge detection of product outer packaging images. In the process of detecting and correcting the blurred edges of product packaging images, new observation data is generated and new parameter filtering is performed at any time on the basis of continuously updating data to realise real-time observation. The fuzzy edge of the product outer packaging image is processed, and the filtering of the fuzzy boundary of the product outer packaging image is realised by updating the optimal image matrix.

Select the appropriate original image of the product outer packaging, and use the NSHP model to calculate the Kalman signal model of the fuzzy edge of the original image of the product outer packaging:

$$H(a,s) = \sum f_d \times H(a-k, s-l) + \varepsilon \tag{10}$$

In formula (10), ε is Gaussian white noise, f_d is the information correlation coefficient between the fuzzy edges of the original image of the product packaging, *H* is the Kalman signal input in the optimal image matrix, *a* and *s* are the edge contour information of the original image of the product packaging respectively, *k* and *l* are the fuzzy edge contour information of the product packaging image, respectively. Through this model, the state equation and observation equation required to establish the Kalman filter are:

$$G(a,s) = DH(a, s-1) + S\varepsilon \tag{11}$$

$$F(a,s) = AH(a,s) + \epsilon \tag{12}$$

In formulas (11) and (12), $G(a,s)$ is the state vector of the blurred edge of the original image of the product packaging, G is the state of blurred edge of the original image of the product outer package, D is the system matrix and G is linearly transformed. $F(a,s)$ is the observation vector, S and A are the system matrix parameters, respectively and ϵ is the observation noise.

Using the state equation and observation equation, a fuzzy boundary state space model outside the product is established and combined with the covariance for optimal output (Oh and Nam, 2021). In this paper, Kalman filtering is used to filter and process the fuzzy edges of product packaging images, so as to achieve fuzzy edge detection of product packaging images. The specific process is as follows:

1) One-step detection of the blurred edge state of the product packaging image, namely:

$$M(i,j) = DG'(\mathrm{a},\mathrm{s}) - 1 + S\omega(i,j) \tag{13}$$

The current state is detected based on the fuzzy edge state of the previous product packaging image. In formula (13), $\omega(i,j)$ is the state control amount, $M(i,j)$ is the optimal product packaging image fuzzy edge detection value, and $G'(a,s)$ is the optimal filtering value.

2) The one-step detection of the fuzzy edge state of the product packaging image means the square error matrix equation, namely:

$$N(i,j) = DF'(a,s-1)D^T + S\varphi S^T \tag{14}$$

This equation is used to update the covariance. In formula (14), $N(i,j)$ is the fuzzy edge detection variance matrix of the product packaging image, $F'(a,s-1)$ is the filter matrix and φ is the observation noise covariance matrix.

3) The updated filter state gain equation is:

$$B(i,j) = N(i,j)A^T\left[AN(i,j)A^T + S\right] \tag{15}$$

In formula (15), $B(i,j)$ is the Kalman filter gain. On this basis, the obtained gain is used as a weight to determine the ratio between the blurred boundary detection of the product outer packaging image and the actual measurement result.

4) The fuzzy boundary of the product outer packaging image is optimally estimated. At this time, the fuzzy boundary state vector of the product outer packaging image is:

$$G'(a,s) = M(i,j) + B(i,j)\times\left[\omega(\mathrm{i},\mathrm{j}) - AM(i,j)\right] \tag{16}$$

When the fuzzy edge detection value in the product packaging image is known, the final estimation is carried out through the filtered mean square deviation matrix equation, that is:

5) Filtering mean square error matrix equation, namely:

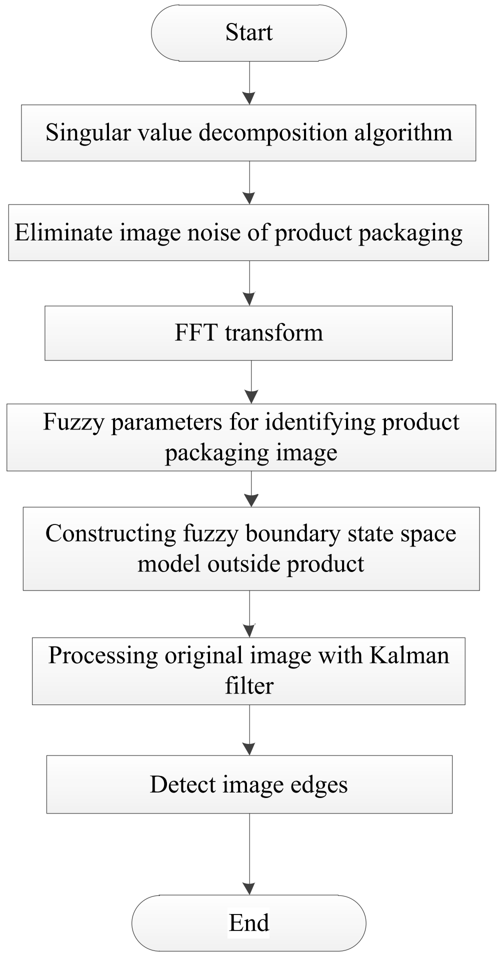
$$N'(i,j) = \left[1 - B(i,j)\times A\right]\times N(i,j) \tag{17}$$

With corrections to the estimates, the next iteration can be conveniently performed. Using the autoregressive method, the optimal image matrix can be obtained.

Owing the large computational load of the Kalman filter algorithm, the NSHP model is used to simplify the algorithm update, thereby speeding up the algorithm’s computational speed. In this algorithm, the algorithm only updates a certain distance of the current pixel and does not need to update all pixels on a large scale, thus significantly saving the computing time and the accuracy will not decrease.

Through the above steps, the blurred edge detection of the product outer packaging image is realised. Figure 1 shows the process of detecting blurred edges of product packaging images.

Figure 1 Flow chart of blurred edge detection of product packaging images



Through the above content, the design of fuzzy edge detection method of product packaging image based on Kalman filter is completed. Singular Value Decomposition (SVD) algorithm is used to remove the noise of product packaging image, which can effectively reduce the impact of noise on the original image; Combined with the nature of FFT transform, the fuzzy parameters of product packaging image are identified to reduce the detection time; The fuzzy boundary state space model outside the product is constructed, and the fuzzy edge of the original image of product packaging is processed by Kalman filter to improve the quality of fuzzy edge detection of product packaging image.

4 Experimental simulation and analysis

4.1 Setting up the experimental environment

In order to verify the effectiveness of the fuzzy edge detection method of product packaging image based on Kalman filter, the image in the product packaging image database of a food processing factory was selected as the experimental object. This experiment is based on MATLAB platform. The operating system is win10 system equipped with i7 processor. In the image database, 1200 images are selected as training set samples and 2500 images as test set samples. The image is converted to Numpy format data, and the image is normalised to obtain the original image library of product packaging and the image library with different noise characteristics. The methods proposed in Versaci and Morabito (2021) and Feng et al. (2021) are selected as the comparison methods and tested together with this method. The application performance of the method proposed in this paper is verified by taking the detection quality, detection effect and detection time of the fuzzy edge of the product packaging image as the experimental test indicators.

4.2 The detection quality of fuzzy edge of product packaging image

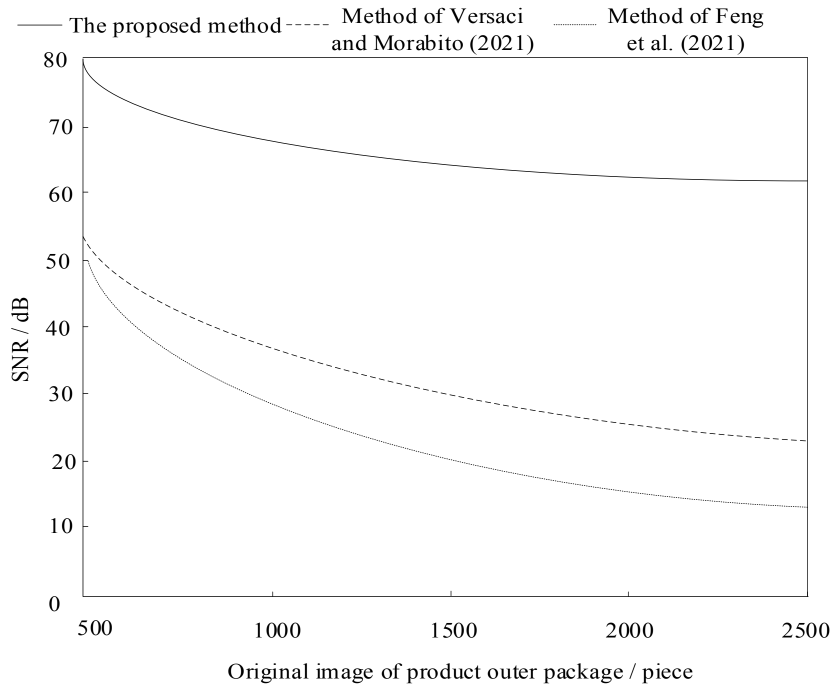
In order to verify the quality of the fuzzy edge detection of the product packaging image by the proposed method, the signal-to-noise ratio was used as the evaluation index. The higher the signal-to-noise ratio, the better the detection quality of the fuzzy edge of the product packaging image. Its calculation formula is as follows:

$$SNR = 10lg\left[\frac{\sum_{n=1}^{M}\sum_{m=1}^{N}k(n,m)^2}{\sum_{n=1}^{M}\sum_{m=1}^{N}\left[k(n,m)-p(z,x)\right]^2}\right] \tag{18}$$

By comparing the method of Versaci and Morabito (2021), the method of Feng et al. (2021) and the proposed method, the signal-to-noise ratios of fuzzy edge detection of product packaging images of different methods are obtained as shown in Figure 2.

According to Figure 2, with the increase of the original image of the product outer packaging, the signal-to-noise ratio of the fuzzy edge detection of the product outer packaging image of different methods decreases accordingly. When the original image of product outer packaging is 2500 pieces, the signal-to-noise ratio of the fuzzy edge detection of the product outer packaging image by the method of Versaci and Morabito (2021) is 22.5 dB, and the signal-to-noise ratio of the fuzzy edge detection of the product outer packaging image of the method of Feng et al. (2021) is 12.5 dB. The signal-to-noise ratio of the proposed method for fuzzy edge detection of product packaging images is as high as 61.5 dB. It can be seen that the signal-to-noise ratio of the fuzzy edge detection of the product outer packaging image of the proposed method is high, indicating that the proposed method has a better quality of the fuzzy edge detection of the product outer packaging image.

Figure 2 Signal-to-noise ratio of fuzzy edge detection of product packaging images with different methods



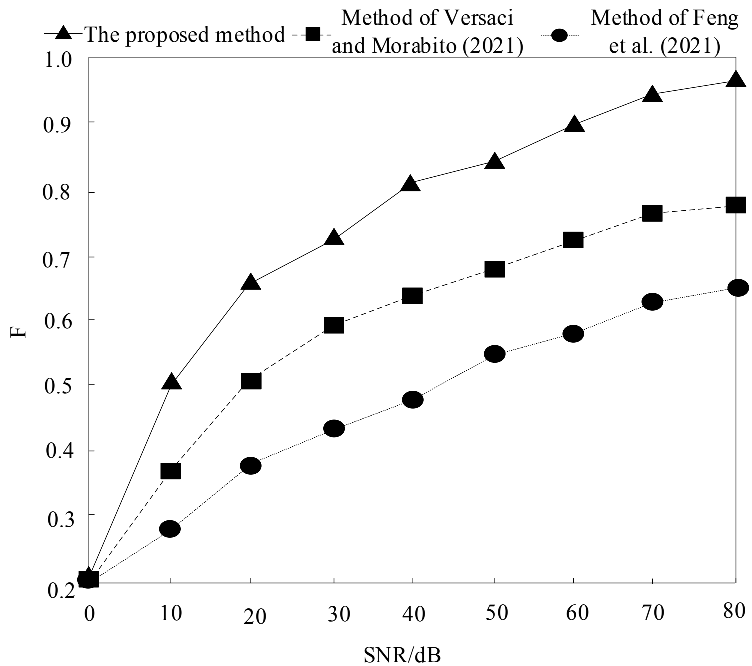
4.3 Fuzzy edge detection effect of product packaging image

To further verify the fuzzy edge detection effect of the proposed method on product packaging images, the quality factor is used as the evaluation index. The higher the quality factor, the better the detection effect of the method on the fuzzy edge of the product packaging image. Its calculation formula is as follows:

$$F = \frac{1}{\text{Max}\left(S_B, S_D\right)} \times \frac{1}{1 + \tau\sigma\left(K\right)} \tag{19}$$

In formula (19), S_B is the number of fuzzy edge pixels in the actual product packaging image, and S_D is the detected number of fuzzy edge pixels in the product packaging image. $\sigma\left(K\right)$ is the distance from the K detected fuzzy edge pixel of the product outer packaging image to the nearest real product outer packaging image fuzzy edge pixel, and τ is a constant coefficient. The method of Versaci and Morabito (2021), the method of Feng et al. (2021) and the proposed method are used to compare and the quality factors of fuzzy edge detection of product packaging images obtained by different methods are shown in Figure 3.

Figure 3 Fuzzy edge detection quality factor of product outer packaging image with different methods



According to Figure 3, with the increase of the signal-to-noise ratio of the fuzzy edge detection of the product outer packaging image, the quality factor of the fuzzy edge detection of the product outer packaging image of different methods increases accordingly. When the signal-to-noise ratio of the fuzzy edge detection of the product outer packaging image is 80 dB, the quality factor of the fuzzy edge detection of the product outer packaging image by the method of Versaci and Morabito (2021) is 0.78, and the quality factor of the fuzzy edge detection of the product outer packaging image of the method of the Feng et al. (2021) is 0.65. The quality factor of the proposed method is as high as 0.97 for fuzzy edge detection of product packaging images. It can be seen that the quality factor of the fuzzy edge detection of the product outer packaging image of the proposed method is higher, indicating that the proposed method has a better effect of the fuzzy edge detection of the outer packaging image of the product.

4.4 Fuzzy edge detection time of product outer packaging image

On this basis, the fuzzy edge detection time of the product outer packaging image of the proposed method is verified. 2500 original product outer packaging images are selected as the experimental object. The detection time of 500, 1000, 1500, 2000 and 5000 original product outer packaging images of the three methods is compared. The shorter the detection time is, the higher the fuzzy edge detection efficiency of the product outer packaging image of the method is. The fuzzy edge detection time of product outer packaging image of different methods is obtained by comparing the methods in Versaci and Morabito (2021), Feng et al. (2021) and the proposed methods, as shown in Table 1.

Table 1 Blurred edge detection time of product packaging images by different methods

Original image of product outer package / piece	*The proposed method/s*	*The method of Versaci and Morabito (2021)/s*	*The method of Feng et al. (2021)/s*
500	7.9	13.2	15.9
1000	10.8	17.9	19.5
1500	13.1	22.1	26.1
2000	16.5	26.8	29.4
2500	19.7	29.3	32.9

According to Table 1, with the increase of the number of original images of product packaging, the fuzzy edge detection time of product packaging images with different methods increases. When the original image of product outer packaging is 2500, the detection time of the fuzzy edge of the product outer packaging image of the method of Versaci and Morabito (2021) is 29.3 s and the detection time of the fuzzy edge of the outer packaging image of the product by the method of Feng et al. (2021) is 32.9 s. However, the detection time of the fuzzy edge of the product packaging image of the proposed method is only 19.7 s. It can be seen that the detection time of the fuzzy edge of the product outer packaging image of the proposed method is short, and the detection efficiency of the fuzzy edge of the outer packaging image of the product can be effectively improved.

5 Conclusions

In order to solve the problems of poor detection quality, poor effect and long time in the existing edge detection methods of product outer packaging image, a fuzzy edge detection method of product outer packaging image based on Kalman filter is proposed.

1 The principle of Kalman filter is analysed, and the singular value decomposition algorithm is used to remove the image noise of product packaging. Quickly identify the fuzzy parameters of product packaging image, filter the fuzzy edge of the original image of product packaging by Kalman filter and realise the fuzzy edge detection of product packaging image.

2 Through the comparative experiment with two existing product packaging image edge detection methods, it can be verified that the signal-to-noise ratio of product packaging image fuzzy edge detection of this design method can reach 61.5 dB, the quality factor is as high as 0.97, and the detection time is only 19.7 s. It is proved that the quality and effect of product packaging image fuzzy edge detection of this method are good, and can effectively improve the efficiency of product packaging image fuzzy edge detection.

3 Owing to the limited time, this method still has some shortcomings. For example, it cannot consider the denoising effect of product packaging image edge detection in high-noise environment. In the next research, we will focus on the impact of the product packaging image edge detection environment, further improve the practical application performance of the design method in this paper and improve the effect of fuzzy edge detection of product packaging image.

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