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# Adaptive Enhancement Method for Robot Sequence Motion Images

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**Abstract**
Aiming at the problems of low image enhancement accuracy, long enhancement time and poor image quality in the traditional robot sequence motion image enhancement methods, an adaptive enhancement method for robot sequence motion image is proposed. The feature representation of the image was obtained by Karhunen-Loeve (K-L) transformation, and the nonlinear relationship between the robot joint angle and the image feature was established. The trajectory planning was carried out in the robot joint space to generate the robot sequence motion image, and an adaptive homomorphic filter was constructed to process the noise of the robot sequence motion image. According to the noise processing results, the brightness of robot sequence motion image was enhanced by using the multi-scale Retinex algorithm. The simulation results showed that the proposed method had higher accuracy and consumed shorter time for enhancement of robot sequence motion images. The simulation results showed that the image enhancement accuracy of the proposed method could reach 100%. The proposed method has important research significance and economic value in intelligent monitoring, automatic driving, and military fields.

**Keywords**
Adaptive Enhancement, K-L Transformation, Multiscale Retinex Algorithm, Robot, Sequence Motion Image

## 1. Introduction

Modern science and technology are constantly improving and updating. Various enterprises have also made different innovations in technology. Intelligence has gradually penetrated into all walks of life and has become an essential condition for modern production methods. In the face of the sudden epidemic situation, mobile robots have become an indispensable demand of people and played a great role in the prevention and control of the epidemic [1]. Zhang et al. [2] pointed out that intelligent devices such as intelligent vehicles, machine vision, and unmanned aerial vehicles (UAVs) played a great role in preventing the spread of viruses. Intelligent devices provide strong technical support for epidemic prevention and control and virus blocking. It can be reported that machine vision also plays an important role in dealing with epidemic prevention and control, such as tracking robot, cargo transport robot, visual guidance robot, patrol alarm robot [3]. Machine vision technology has been used in these aspects. The development of robot control technology is very stable and mature [4]. Moreover, the research on machine vision based on mobile robot platform, especially the research on moving target detection and


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accurate tracking, has attracted more and more attention of relevant researchers.

Reference [5] proposes a moving image enhancement method based on adaptive residuals. An adaptive residuals module composed of deformation convolution module and channel attention module was constructed in the generation network. The deformation convolution module learns the shape variables of motion blurred image features, which can dynamically adjust the shape and size of convolution kernel according to the image deformation information, so as to improve the ability of the network to adapt to image deformation. The channel attention module adjusts the channel of the extracted deformation features to obtain more high-frequency features of the image and enhances the texture details of the restored image. Reference [6] proposes an edge sharpening and enhancement method for digital images based on motion blur. Firstly, the whole image was sharpened by the anti-sharpening mask method. At the same time, the Sobel operator in the first derivative was used to detect the edge image threshold so as to reduce the high-frequency noise component. Then, the image edge was sharpened separately according to the differential properties of the slope edge. Secondly, the image was decomposed by the total variation method through the differential structure. Finally, the research problem was regarded as a normal process of forward diffusion in the scale space. At the same time, the monitoring diffusion threshold was set to reduce the ringing effect and complete the edge sharpening and enhancement. However, the accuracy of the above two methods for moving image enhancement was low, resulting in poor enhancement effect. Reference [7] proposes an intelligent enhancement method for target motion trajectory of video surveillance image based on histogram equalization. The relative distance measurement method was used to extract the change distance and angle of the current video surveillance image relative to the previous frame image in real time, and the image target motion trajectory was obtained through sequential calculation. The adaptive local histogram equalization method was used to select the appropriate rectangular window size and calculate the matrix window histogram. The histogram was equalized to update the gray value of the central pixel of the target motion trajectory, thus realizing the intelligent enhancement of the target motion trajectory.

Aiming at the problems of low enhancement accuracy and poor enhancement effect of motion images in the above-mentioned literature methods, an adaptive enhancement method of robot sequence motion images was proposed. The Karhunen-Loeve (K-L) transform method was used to generate the robot sequence motion images, the polynomial function interpolation method was used for trajectory planning, and an adaptive homomorphic filter was constructed to deal with the noise of the robot sequence motion images. The multi-scale Retinex algorithm was used to enhance the robot sequence motion images.

# 2. Adaptive Enhancement Method for Robot Sequence Motion Images

## 2.1 Robot Sequence Motion Image Generation

The K-L transformation method, also known as the eigenspace method, compresses the image by extracting the main components of the image [8]. Consider $p$ gray scale image of $q_1 * q_2$. Each image can be expressed as a vector $I_p$, $p = 1,2,\ldots,P$ with $N = q_1 * q_2$ elements, or as a point in the $N$-dimensional Euclidean space $R^N$. Calculate the average image using the following formula:

$$\bar{I} = \frac{1}{P}\sum_{p=1}^{P} I_p. \quad (1)$$

Then $p$ difference diagram is obtained:

$$\Delta I_p = I_p - I. \quad (2)$$

Its covariance matrix is:

$$C = \frac{1}{P}AA^T, \quad (3)$$

where $C$ is a real symmetric matrix. Find the eigenvector $e_i, i = 1,2,\dots,M$ corresponding to $M$ larger eigenvalues of matrix $C$.

$$\lambda e_i = Ce_i. \quad (4)$$

where

$$M < P < N. \quad (5)$$

These $M$ feature vectors constitute the orthogonal basis of the original image, which is called eigen-images. Since $M < N$, the purpose of image compression is achieved.

The $U$ matrix is constructed from these $M$ eigenvectors:

$$U=(e_1, e_2, \dots, e_M). \quad (6)$$

An image $I \in R^N$ can be represented by an $U$ matrix as follows:

$$Y = U^T(I - \bar{I}), \quad (7)$$

where $U \in R^M$ is called image feature, which is the compressed representation of an image.

According to the above relationship between robot joint angle and image features, the process of generating robot sequence motion images is shown in Fig. 1, which includes trajectory planning, feature vector sequence generation, and image sequence synthesis.

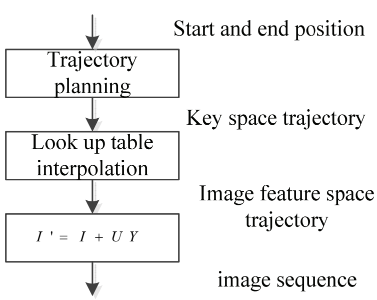


**Fig. 1.** Robot sequence motion image.

It is usually expected that the motion of the manipulator is smooth, that is, it has a continuous first-order derivative, and sometimes it is even required to have a continuous second-order derivative [9]. The non-smooth movement is easy to cause the wear and damage of the mechanism, and may even excite the vibration of the manipulator. The task of planning is to plan the smooth trajectory through these points according to the given path points. In this paper, the method of polynomial function interpolation was used for trajectory planning [10].

For each point on the joint space trajectory, the corresponding point in the image feature space can be found by looking up the table or interpolation from Table 1. In this way, the motion trajectory in joint space can be transformed into the motion trajectory in image feature space.

Using the results of K-L transformation, the motion trajectory in the image feature space was generated into an image sequence through formula $I' = I + UY$, that is, the virtual motion of the robot.

**Table 1.** Relationship between robot joint angle and image features

| Location of $\theta_2$ | Location of $\theta_1$ | | | |
|---|---|---|---|---|
| | 1 | 2 | ⋯ | $N_1$ |
| 1 | $Y_1$ | $Y_2$ | ⋯ | $Y_{N_1}$ |
| 2 | $Y_{N_1+1}$ | $Y_{N_1+2}$ | ⋯ | $Y_{2N_1}$ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| $N_2$ | $Y_{(N_2-1)N_1+1}$ | $Y_{(N_2-1)N_1+2}$ | ⋯ | $Y_{N_2N_1}$ |

## 2.2 Noise Processing of Robot Sequence Motion Image

According to the robot sequence motion image obtained above, an adaptive homomorphic filter was constructed to process the noise of the robot sequence motion image.

In homomorphic filtering algorithm, the performance of high-pass filter determines the overall processing effect of the algorithm, so the selection of high-pass filter should comprehensively consider the advantages and characteristics of various filters, and the system function of homomorphic filtering should comply with the rules shown in Fig. 2.

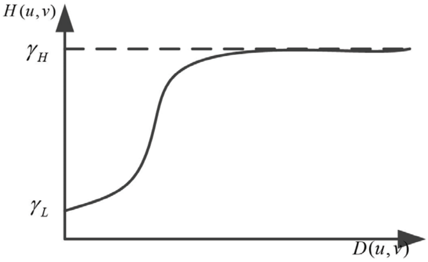


**Fig. 2.** Homomorphic filtering system function.

In Fig. 2, $\gamma_H, \gamma_L$ represents the high-frequency gain and low-frequency gain coefficients respectively, where $\gamma_H > 1$ and $\gamma_L < 1$ control the whole system function within this range, $D(u, v)$ is the distance from the frequency point to the center, which can be expressed as follow:

$$D(u,v)=\{(u-P/2)^2+(v-Q/2)^2\}^{1/2}, \tag{8}$$

where $P$ and $Q$ represent the number of rows and columns of the robot sequence motion image, respectively. The commonly used high-pass filter types include Gauss type, Butterworth type, and exponential type.

### 2.3 Adaptive Enhancement of Robot Sequence Motion Images based on Multi-scale Retinex Algorithm

On the basis of the above noise processing of robot sequence motion images, the multi-scale Retinex algorithm was used to enhance the brightness of robot sequence motion images. Through the improved multi-scale decomposition method, the robot sequence motion image was divided into incident component and reflection component, and the proportion of incident component and reflection component was adjusted. The output value of multi-scale Retinex is basically a combination of single-scale Retinex with multiple weight functions. The calculation formula of the algorithm is:

$$R_i^{MSR}(x,y) = \sum_{s=1}^{S} w_s R_{i,s}^{SSR}(x,y), \tag{9}$$

where $R_i^{MSR}$ is the output value of the $i$-th color channel of multi-scale Retinex, $S$ is the number of scales, $w_s$ is the weight of each scale, and $R_{i,s}^{SSR}$ is the output of single-scale Retinex on each scale. The multi-scale Retinex Gaussian filter estimates local illumination through low frequency, medium frequency, and high frequency. The surrounding function of each scale is:

$$F_s(x,y) = K_s e^{-(x^2+y^2)/\sigma_s^2}, \tag{10}$$

## 3. Simulation Experiment Analysis

In order to verify the effectiveness of the adaptive enhancement method for robot sequence motion image proposed in this paper in practical application, experiments were conducted by using Dajiang aerial robot. The number of experimental iterations was 100. The aerial robot is shown in Fig. 3.

Parameter settings of aerial robot are shown in Table 2.

**Fig. 3.** Aerial robot.

**Table 2.** Parameter setting of robot arm

| Parameter | Value |
|---|---|
| Learning rate of value function | $1 \times 10^{-4}$ |
| Strategy learning rate | $1 \times 10^{-5}$ |
| Single time step duration | 100 |
| Maximum time steps of an episode | 1,000 |
| Total training time steps | $2 \times 10^5$ |
| Parameter optimizer | Adam |
| Initial joint position | random |
| Initial joint velocity | [0,0,0,0,0,0,0] |

The image enhancement accuracy of the proposed method, the method in reference [5], and the method in reference [6] are comparatively analyzed. The experimental results are shown in Fig. 4.

According to Fig. 4, the precision of image enhancement by the proposed method could reach 100%, while the precision of image enhancement by the method in reference [5] was only 80%, and that by the method in reference [6] was only 90%. The precision of image enhancement by the proposed method was the highest and the enhancement effect was the best.

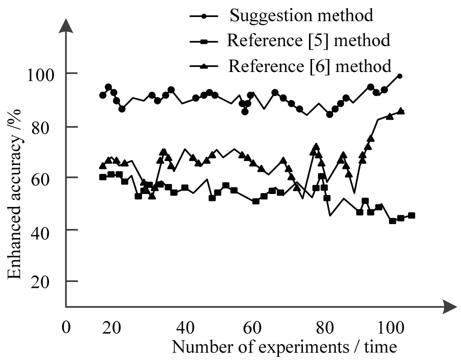


**Fig. 4.** Comparison results of adaptive enhancement accuracy of robot sequence motion images of three methods.

## 4. Conclusion

Vision is one of the main ways for human beings to obtain information. According to relevant research, more than 80% of human perception of external things is obtained through vision. It has always been a human dream to produce highly intelligent robots to replace human labor. The intelligence of robot depends on the ability of information interaction with the surrounding environment to a certain extent. Therefore, external sensors have been active as a bridge between the robot and the surrounding environment, where vision sensor is a very important one. Computer vision is a subject that simulates the ability of human visual mechanism to acquire and process information. The research goal of computer vision is to make meaningful judgments on actual objects and scenes based on the sensed images. Computer vision system collects images or image sequences through visual sensors, processes them, analyzes and understands the information that can be processed by computers or robots. Computer vision, expert system and natural language understanding have become the three most active fields in artificial intelligence. Due to the incompleteness of camera tools, processing methods and storage devices, as well as the influence of target offset, distortion and spatial ray noise, unpredictable factors often appear in the process of image processing and storage, which brings great inconvenience to people's understanding of image information. Therefore, how to properly process the robot sequence motion images and how to extract the effective information from the robot sequence motion images have become an urgent problem. In this paper, an adaptive enhancement method for robot sequence motion images was proposed, and the simulation results showed that the image enhancement accuracy of the method in reference [5] was only 80%, and that of the method in reference [6] was only 90%. Compared with the two methods, the adaptive enhancement method of robot sequence motion images proposed in this paper had higher image enhancement accuracy and better enhancement effect, which is of important research significance and economic value in intelligent monitoring, automatic driving, and military fields.

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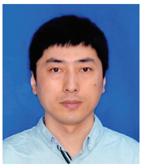

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