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Literature Review on Attention Based Image Enhancement Techniques

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Abstract. This paper reviews advances in attention-based image enhancement techniques in the field of character motion synthesis and enhancement. With the development of deep learning, attention mechanisms have the potential to mimic the ability of the visual system to attend to important information. In this area, it is used to deal with noise, occlusion, and other problems in motion capture data. Spatial attention models can recognize critical joint angles and trajectories to generate smoother, more realistic movements. Temporal attention mechanisms can recognize continuity and patterns in movements, improving the quality of synthesis. Generative models (e.g., attention-based generative adversarial networks) can learn to pay attention to key features, synthesize actions appropriate for specific scenes and styles, and enhance the immersion and believability of virtual environments. In addition, in terms of action retargeting, attention techniques can preserve salient motion features and adapt to the differences between characters. In terms of physical simulation optimization, the attention algorithm reduces computational cost, improves simulation accuracy, and achieves real-time generation of high-fidelity character actions.

Keywords: Attention Mechanisms, Deep Learning Architectures, Degraded Image Enhancement, Generative Adversarial Networks, Computer Vision Applications

1. Introductory

In the continuous evolution and expansion of the field of character motion synthesis, the attention mechanism is deeply inspired by the ability of the human visual system to accurately focus on key regions and efficiently filter redundant information, and has achieved outstanding results in the fields of computer vision and image processing. Aiming at the severe challenges faced by motion capture systems, such as sensor layout limitations, noise interference, occlusion dilemma, and data loss due to environmental constraints, we have deeply explored the path of deep integration of the attention mechanism with deep learning architectures, and provided innovative solutions for image and motion optimization, especially in the field of character motion synthesis and enhancement.

In this paper, I will first introduce the outstanding achievements of the attention mechanism inspired by the human visual system in the field of character motion synthesis, as well as the serious challenges faced by motion capture systems, and explore the paths for deep integration of the attention mechanism with deep learning architectures, and the importance of providing innovative solutions for image and motion optimization, especially in the field of character motion synthesis

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and enhancement. Afterwards, I will compare the advantages and disadvantages of various methods of enhancement and summarize them.

This paper depicts a grand blueprint for integrating the attention mechanism into the deep learning framework in the field of character action synthesis. Subsequently, the specific application strategies of the attention mechanism are systematically elaborated from the aspects of enhancing the processing efficiency of motion capture data, constructing an attention-oriented generation model, optimizing the technical means of action redirection, and improving the efficiency of character action simulation. In addition, this paper also reiterates that the integration of the attention mechanism into the technical system of character action synthesis and reinforcement has far-reaching strategic significance and positive impetus for accelerating the pace of technological innovation and development in this field.

2. A recurrent neural network based approach

2.1. Autoregressive RNN

Wenjing Wang et al [1] systematically studied visual perception and understanding techniques in harsh scenes. The study proposed innovative solutions for complex environments such as low illumination, blur and noise. A comprehensive framework was constructed by combining multi-scale feature extraction and attention mechanisms with deep learning. The framework performs well in dealing with different types of image quality degradation, especially in preserving image details and improving overall visual quality.

Jongwon H et al [2] explored the innovative application of deep learning in street view image enhancement. The study evaluated the impact of different data enhancement techniques on building feature detection through large-scale comparative experiments. A complete image enhancement solution was developed by innovatively combining geometric transformation with illumination adjustment. Experimental results show that the method can effectively improve the accuracy of building feature detection, especially under complex illumination and observation conditions. This research provides a new technical idea for urban building image analysis, which is of great significance for the construction of smart cities.

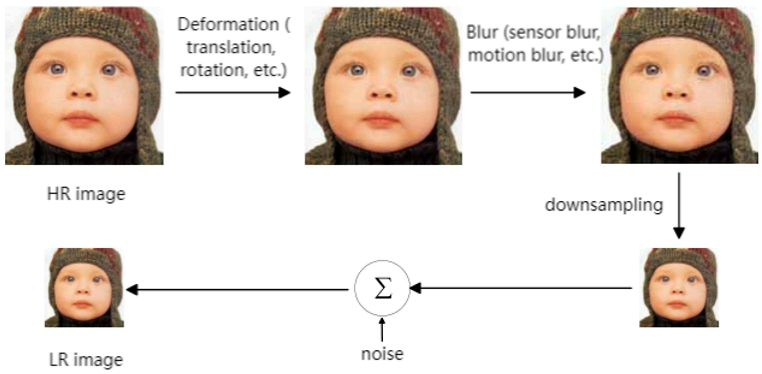


Figure 1. Image downsampling frame

Wang Yaru et al [3] designed a multilayer CNN network structure for underwater image enhancement problem. The study proposes a targeted image quality enhancement scheme by deeply analyzing the characteristics of underwater imaging. The network structure contains multiple feature extraction layers and enhancement layers, which can effectively deal with the problems of color

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distortion, low contrast and blurred details in underwater images. Experiments have proved that the method has obvious advantages in improving the clarity and color reproduction of underwater images, providing reliable technical support for underwater image processing.

Peng Yaru [4] studied the deep learning based image enhancement technique for industrial defect detection. By constructing a specialized neural network model, accurate recognition and enhancement of defects on the surface of industrial products can be achieved. While maintaining the overall characteristics of the image, the method highlights the feature information of the defective region, which significantly improves the sensitivity of the detection system. The research results have been validated in several industrial quality inspection scenarios and have good practical value and promotion prospects.

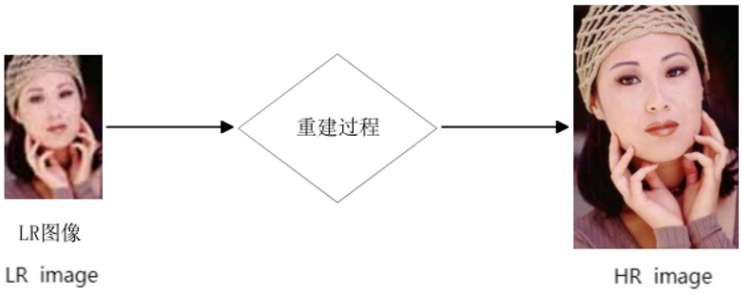


Figure 2. Image super-resolution reconstruction

Chang Qingqing [5] proposed an unsupervised low-light image enhancement method based on Zero-Unet. The study achieved more efficient image enhancement by improving the network structure.Zero-Unet network innovatively introduces a zero-reference learning mechanism on the basis of maintaining the advantages of the original Unet structure, so that the model can realize adaptive enhancement without reference images. Experiments show that this method has excellent image processing effect in low illumination scenes, especially in detail preservation and noise suppression.

Wang [6] explored the deep integration of underwater image enhancement and super-resolution techniques. The study realized image quality improvement and resolution enhancement by designing a multi-task learning framework. The method cleverly combines the loss functions of both image enhancement and super-resolution tasks, and improves the processing effect through joint optimization. Experimental results show that the method not only improves the clarity of underwater images, but also effectively improves the representation of image details.

VeriSilicon [7] has made an innovative breakthrough in the field of AI-ISP technology. By combining AI technology with traditional ISP processing flow, this research has developed a new generation of image signal processing solutions. This method can adaptively adjust the processing parameters to obtain high-quality image results in different scenes. Experiments have demonstrated that the AI-ISP technology has significant advantages in image noise suppression, detail enhancement and color reproduction.

Pan Shan et al [8] proposed a low illumination self-supervised image enhancement method based on structure and texture perception. The study specifically designed the feature extraction and enhancement strategy for the special characteristics of underground environment. By analyzing the structural and textural features of the image, a more accurate enhancement effect is achieved. The method greatly improves the visibility of underground environment images while maintaining the authenticity of the images, which provides important support for underground engineering detection.

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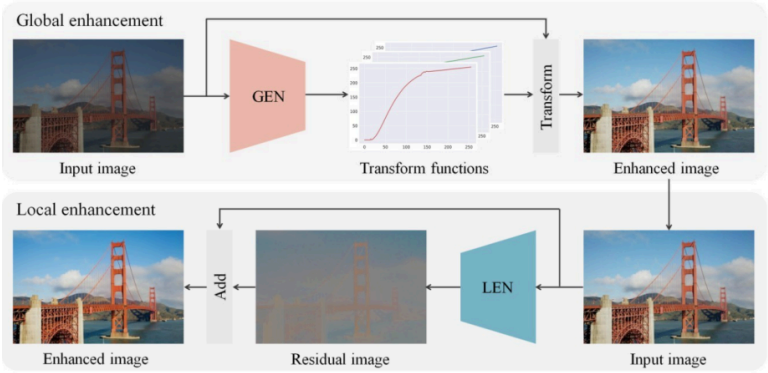


Figure 3. Image data enhancement

Tao Wang [9] studied the application of multi-task learning framework in image processing. The study innovatively combined image segmentation and enhancement tasks to improve processing efficiency through shared feature learning. The framework design includes multiple task branches, each of which is optimized for a specific objective, while the feature-sharing mechanism achieves mutual promotion between tasks. Experimental results show that the method not only improves the image enhancement effect, but also significantly improves the segmentation accuracy.

Han Yuqi [10] proposed a low illumination image enhancement method based on multi-scale feature network. The study realized the effective fusion of different scale information by designing a multi-scale feature extraction module. The network structure captures both local details and global information of the image and improves the enhancement effect by feature fusion strategy. Experimental validation shows that the method effectively improves the image quality under low-light conditions while maintaining the image details.

Mengfei Wu [11] developed an unsupervised image enhancement method based on spatial and channel attention mechanisms. The study achieved more accurate feature enhancement by introducing a dual attention mechanism. The method can automatically identify and enhance the important regions in the image, while adjusting the importance weights of the features through the channel attention mechanism. Experimental results show that the method achieves excellent performance on several benchmark datasets.

Han Fenggang [12] proposed an innovative solution to the backlight image enhancement problem. In this study, an adaptive light compensation mechanism is designed to effectively improve the image quality in backlight scenes. The method can accurately estimate the scene light distribution and compensate accordingly, avoiding the problem of over-enhancement or under-enhancement in traditional methods. Experiments demonstrate that the method performs stably when dealing with various backlit scenes.

Song [13] studied the application of attention mechanism in face image enhancement. By introducing a multi-level attention mechanism, the clarity and details of face images were improved. The method pays special attention to feature extraction and enhancement of key regions of the face, and achieves a more natural enhancement effect by accurately assigning attention weights. Experimental results show that the method has significant advantages in face recognition and analysis tasks.

Lei Wang [14] proposed an algorithm for low light conditions based on the attention mechanism. The study achieved a more accurate local enhancement effect by designing an attention module with an adaptive region. The method can automatically adjust the enhancement intensity according to the

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image content, avoiding the distortion problem caused by global enhancement. Experiments prove that the algorithm can realize stable enhancement effects in various low-light scenes.

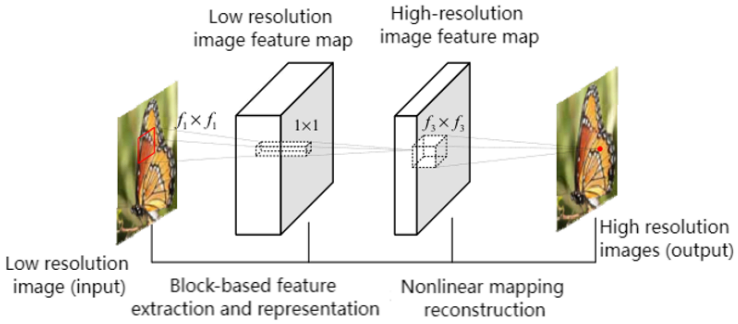


Figure 4. SRCNN structure

Wang Yibo et al [15] developed an adaptive vision SLAM low-light image enhancement algorithm. The study proposed a real-time adaptive enhancement solution for the performance of SLAM system in low illumination environment. The algorithm dynamically adjusts the enhancement parameters by analyzing the distribution of image feature points and lighting conditions, which effectively improves the localization accuracy and robustness of the SLAM system in low-light environments. Experimental results show that this method significantly improves the overall performance of the SLAM system.

Fanyu Zeng [16] proposed a new method for low illumination image enhancement based on Transformer architecture. The study innovatively applies the long-range dependence property of Transformer to the field of image enhancement, capturing global illumination information through a self-attentive mechanism. The method breaks through the limitation of the local receptive field of the traditional convolutional network, and can better handle complex lighting scenes. Experimental validation shows that the method has excellent enhancement effect and generalization ability.

Hao Xu [17] studied the feature fusion method for face detection under low light conditions. The accuracy of face detection was improved by designing a multi-level feature fusion strategy. The method can effectively integrate different levels of feature information and improve the model's ability to detect faces at different scales and under different lighting conditions. The experimental results demonstrate the superiority of this method in practical applications.

Wenqi Lu [18] proposed a 3D point cloud image reconstruction technique for low illumination scenes. The study greatly improved the accuracy of 3D reconstruction by improving the quality of low illumination images. The method innovatively combines image enhancement with point cloud reconstruction to solve the problem of insufficient feature extraction in low illumination environments. Experiments show that the technique achieves good results in the reconstruction of complex indoor and outdoor scenes.

Zhang [19] studied the underwater target recognition method based on IACE technology. By improving the image enhancement algorithm, the recognition rate of underwater targets was improved. In this study, a special image preprocessing process is designed for the special characteristics of underwater imaging, which effectively solves the problems of underwater image blurring and color deviation. Experimental results show that the method significantly improves the accuracy of underwater target recognition.

Junjun Niu [20] proposed a GAN based image enhancement and restoration method. The study improves image quality while maintaining image details by designing a novel generative adversarial

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network structure. The method pays special attention to the naturalness and authenticity of the image and achieves high quality image enhancement through adversarial learning. Experiments have demonstrated that the method performs well in dealing with a wide range of poor quality images.

Tao Wang [21] studied a cooperative optimization method for image segmentation and enhancement. The method realized the mutual promotion of segmentation and enhancement tasks by constructing a multi-task learning framework. The method innovatively designs a feedback mechanism between tasks so that the two tasks can promote each other and improve the overall performance. The experimental results demonstrate the effectiveness and practical value of the method.

2.2. Recurrent transition network

The recursive transition network is particularly suitable for handling character movement on uneven terrain. It employs an encoder-recursive-decoder structure that efficiently generates inter-frame transition motions from the start point to the end point. This approach does not require manual labeling of gaits or frames, but requires high-quality training data. Since it is a unidirectional synthesis, it needs to be blended with the target frame at the end of the synthesis to ensure the continuity of the motion.

In complex games and virtual reality scenarios, recursive transformation networks are used to generate character actions adapted to different terrain conditions, thus enhancing game immersion and realism. However, the method may not perform well when dealing with extreme terrain changes or unknown environments.

Liu Yuhong [22] studied the image enhancement and quality evaluation methods based on biological visual perception mechanisms. The study deeply analyzed the working principle of the human visual system and proposed an enhancement algorithm that conforms to the characteristics of visual perception. By simulating the human eye's perception mechanism of brightness, contrast and color, a more natural image enhancement effect is achieved. The results of the study show that the method obtains a high score in subjective visual quality evaluation.

Yang Wei [23] proposed an image enhancement algorithm based on visual perception features. Through in-depth understanding of the characteristics of the human visual system, the study designed an adaptive enhancement strategy. This method can dynamically adjust the enhancement parameters according to the visual features of different scenes, avoiding the problem of over-enhancement in traditional methods. Experimental validation shows that this algorithm has obvious advantages in maintaining the naturalness of images.

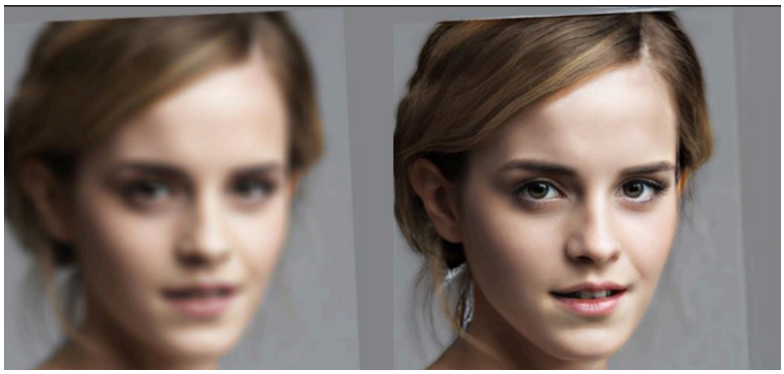


Figure 5. Blurred light image enhancement method

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Yangping Chen [24] developed an image detail enhancement method for interior art design. The research is based on visual perception theory, with special attention to the detail performance in art design. The method realizes the processing effect of enhancing details while maintaining artistic sense by analyzing the characteristics of human visual perception of artworks. The experimental results prove that the method has unique advantages in the field of art design.

Lin Wei et al [25] proposed an image enhancement scheme based on visual communication technology. The study developed a specialized image quality optimization method for the special needs of visual communication systems. The method analyzes the characteristics of visual information transmission and achieves efficient image enhancement and compression transmission. Experiments show that the technique achieves significant results in improving communication efficiency and image quality.

Wu, Wenyong et al [26] studied image enhancement techniques under low illumination environment. Through an in-depth study of the principles of visual communication, a new image processing method under low illumination conditions was proposed. The study focuses on the effective transmission of information and significantly improves the image quality under low illumination conditions by optimizing the transmission process of image information. The experimental results prove that the method works well in practical applications.

Lu Chuchen et al [27] proposed an image enhancement method under blurred lighting conditions. The study establishes a blur assessment model to realize adaptive image sharpness processing. The method can accurately assess the degree of blur in different regions and enhance them accordingly, and performs well under complex lighting environments. Experimental validation shows that the method is highly practical.

Yi Li [28] developed a visual model-based infrared image enhancement technique. The study proposed a highly adaptable enhancement algorithm by analyzing the perception characteristics of the human visual system on infrared images. This method is especially suitable for the application of night vision system and can effectively improve the visual effect of infrared images. The experimental results show that the technology has important application value in military and security fields.

Wei Yu [29] investigated a fuzzy laser image enhancement method based on visual communication. By improving the clarity of laser imaging, the performance of laser communication system is significantly improved. The method innovatively applies the theory of visual communication to laser image processing, which solves the limitations of traditional methods in processing laser images. The experiment proves that the technique has a broad application prospect in the field of laser communication.

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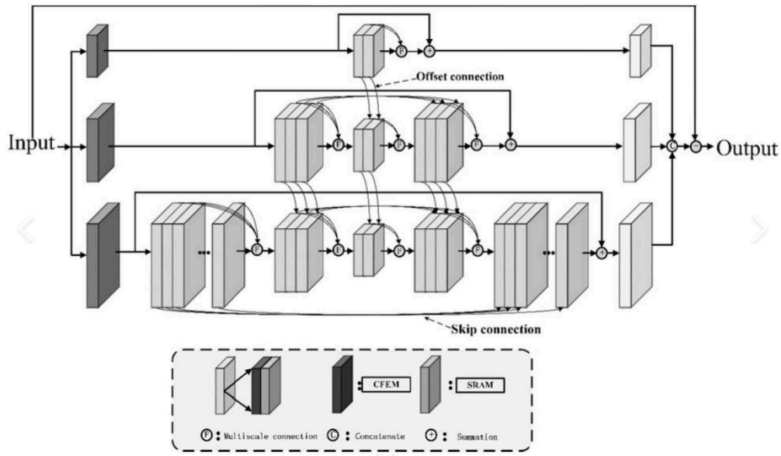


Figure 6. Capsule endoscopy image enhancement method

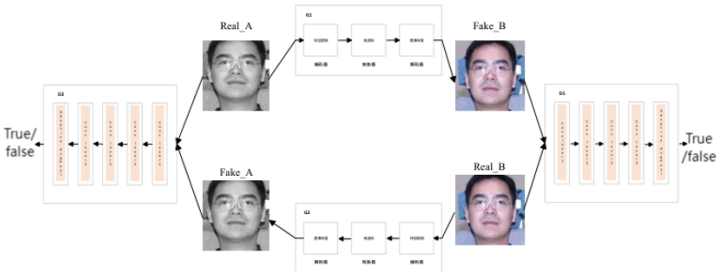


Figure 7. CycleGAN network model

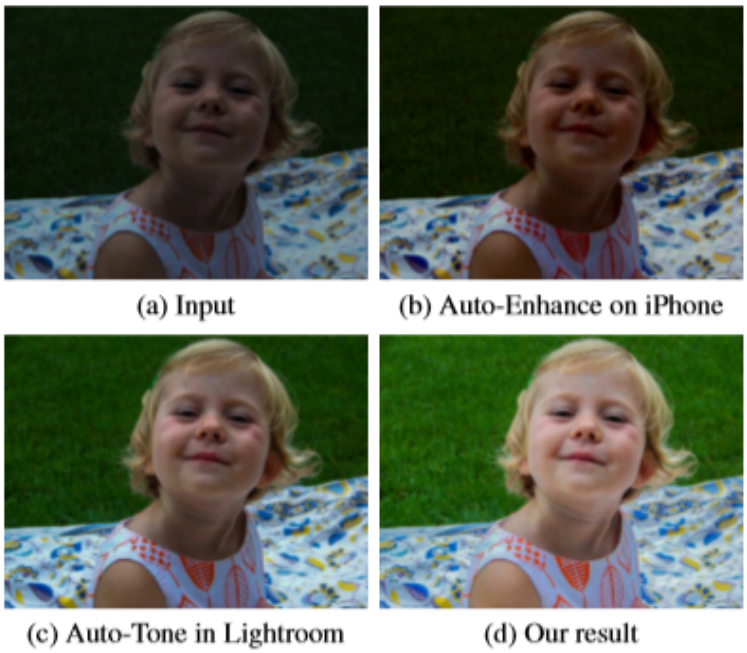


Figure 8. Low light image enhancement

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2.3. Convolutional Neural Network (CNN)

Songlin Li [30] developed a low light image enhancement method based on EnlightenGAN. The study innovatively improved the GAN network structure to improve the brightness while maintaining the naturalness of the image. By designing novel discriminator and generator structures, the method achieves a more stable training process and better enhancement effect. Experimental results show that the method outperforms traditional methods in terms of subjective visual quality and objective evaluation indexes.

Yuanbin Wang [31] proposed a CycleGAN-based algorithm for underground low-light image enhancement. The study optimizes the network structure by combining the attention mechanism and caveolae convolution. The method is especially designed for the special lighting conditions of underground environments and achieves more accurate image enhancement results. Experimental validation shows that the algorithm has significant advantages in image processing for underground scenes.

Luo et al [32] developed an image enhancement method for water level sensors. The study utilized GAN technique to improve the accuracy of water level readings. The method improves the image quality through adversarial training while maintaining the accuracy of key information, providing reliable technical support for water level monitoring. The experimental results demonstrate that the method performs well in practical engineering applications.

Renjun Wang [33] studied GAN based low illumination image enhancement technique. Adversarial training improved the realism and naturalness of the enhancement results. The method innovatively designs a loss function to balance the relationship between image brightness enhancement and detail preservation. Experiments show that the method can obtain stable enhancement results in various low-light scenes.

Shujuan Wu et al [34] applied CycleGAN to industrial inspection. The study improved the accuracy and reliability of the inspection system by improving the network structure. The method innovatively combines image enhancement with industrial inspection tasks, which significantly improves the system performance. Experimental validation shows that this technique has significant value in practical industrial applications.

Yanmei Li [35] systematically studied the basic theory of image enhancement. The advantages and disadvantages of various enhancement methods were comprehensively analyzed, providing an important theoretical basis for subsequent research. The study delves into the principles and technical development trends of image enhancement, which is of great significance in guiding the development of the field.

Xin Xu [36] explored innovative theoretical approaches to image enhancement. He proposed a variety of innovative enhancement algorithms, which had a profound impact on the field of image enhancement. This study systematically summarizes the development of image enhancement techniques and proposes new research directions. The experimental results verify the effectiveness of these theoretical approaches.

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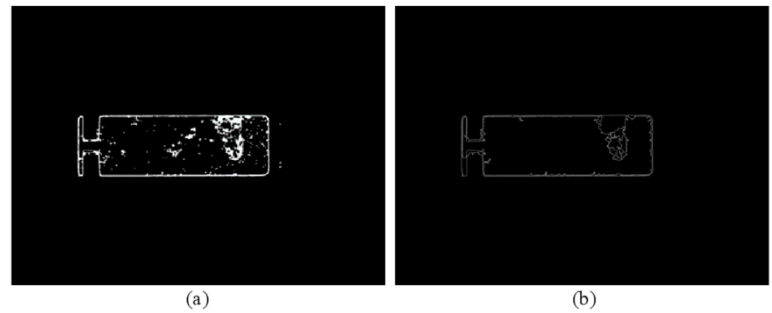


Figure 9. Image enhancement of surface defects of parts

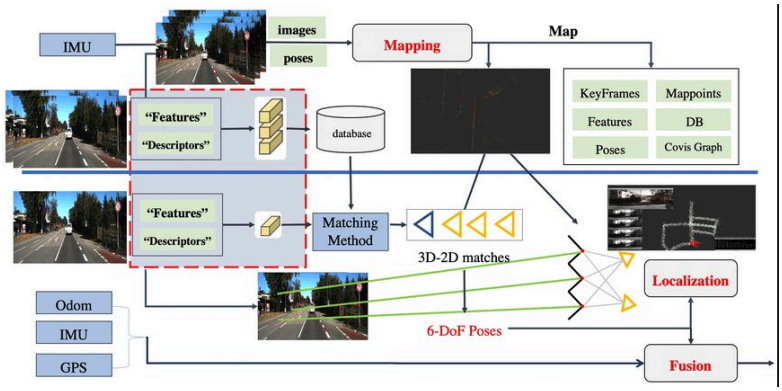


Figure 10. CNN feature extraction

Zihao Ding [37] investigated a feature-preserving image enhancement method. By designing a feature-preserving loss function, the image brightness is enhanced while maintaining the integrity of key features. The method pays special attention to the preservation of image details and avoids the problem of feature loss in traditional enhancement methods. Experiments demonstrate that this method has significant advantages in preserving image details.

Xian Li [38] proposed a color image enhancement method that preserves important features. The study employs a well-designed feature protection mechanism to enhance the visual effect of the image while ensuring that the critical feature information is not distorted. The method innovatively introduces a feature importance assessment module to realize an adaptive feature protection strategy. Experimental results show that the method has unique advantages in the field of color image enhancement.

Zhu Xiangkun et al [39] developed a low illumination image enhancement technique based on multi-scale fusion. By designing a multi-scale fusion strategy with adaptive weights, the enhancement effect is effectively improved. The method can maintain the image features at different scales and achieve a balance between detail enhancement and noise suppression. Experimental validation shows that the method can retain image features well.

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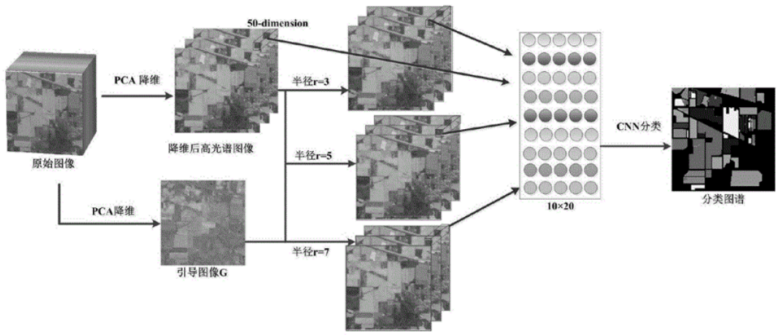


Figure 11. Multi-scale fusion techniques

Wang Xincheng [40] studied the bird target detection technique based on image enhancement. By optimizing the image features, the detection rate under complex background was improved. The method pays special attention to the preservation and enhancement of target features, which ensures the detection accuracy while maintaining the naturalness of the image. The experimental results prove the practical value of the method.

Peixuan Liu [41] proposed a special endoscopic image enhancement algorithm. This study developed an enhancement method that maintains the characteristics of lesions by combining the special needs of medical images. The technique ensures the accuracy of key diagnostic information while improving image quality, providing strong support for clinical diagnosis.

Luo Ying et al [42] conducted an in-depth experimental validation study. Through systematic comparative experiments, the feasibility of the feature retention method in practical engineering is proved. The study analyzes in detail the feature retention effect in different scenarios, which provides an important reference for the practical application of the method.

Dekuan Song et al [43] studied the feature preservation enhancement technique for remote sensing images. By optimizing the extraction and preservation mechanism of remote sensing features, the accuracy of mapping was improved. The method pays special attention to the preservation of features, which enhances the visual effect of the image while ensuring the accuracy of geographic information. Experiments show that this technique has important value in remote sensing applications.

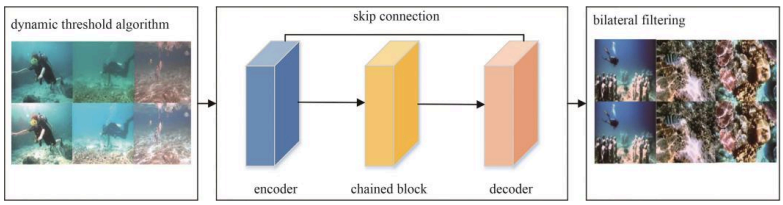


Figure 12. Underwater image enhancement methods

2.4. Generative Adversarial Networks (GANs)

Chen Yuhan [44] investigated the cross-modal image enhancement and fusion method in low illumination environment. Through multimodal information fusion, the image quality in low illumination scenes was significantly improved. The method innovatively combines the complementary information of different modalities to achieve more comprehensive scene understanding and enhancement. Experimental results demonstrate the superiority of the method in complex environments.

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Luo et al [45] proposed a fusion method of infrared and visible images combining image enhancement and multiscale decomposition. The study achieved a better fusion effect through multi-scale feature extraction. The method effectively solves the problem of information loss in cross-modal fusion, while retaining the advantageous features of each modal image. Experimental validation shows that the technique has a broad application prospect in the field of night vision and surveillance.

Dekuan Song et al [46] optimized remote sensing image processing techniques. By using multi-scale fusion and detail enhancement techniques, the clarity of remote sensing images was significantly improved. The method pays special attention to maintaining and enhancing the feature characteristics, which improves the visual effect of the image while ensuring the accuracy of the geographic information. The experimental results show that the method has important application value in the field of remote sensing mapping.

Gong Ximeng et al [47] explored image enhancement and optimization based on 3D laser vision technology. By combining laser scanning data, more accurate graphic design optimization was achieved. The method innovatively integrates 3D spatial information and 2D image information, providing more comprehensive scene understanding. Experiments have demonstrated the unique advantages of this technique in industrial design and architecture.

Xinyong Deng [48] investigated the application of structured light image enhancement technology in high-precision 3D reconstruction. The accuracy of 3D reconstruction was improved by improving the clarity of structured light patterns. The method developed a special image preprocessing algorithm for the characteristics of structured light imaging, which effectively improved the reconstruction quality. Experimental results show that the method significantly improves the accuracy of 3D reconstruction.

Ma Shilong [49] proposed an image enhancement and stitching technique based on an underwater imaging model. Through the guidance of the physical model, the underwater image processing can be realized more accurately. The method considers the characteristics of underwater light propagation and innovatively designs an image quality optimization strategy. Experimental validation shows that the technique has important application value in the fields of underwater archaeology and ocean exploration.

Yaqi Li [50] studied a method of image enhancement for clothing design based on augmented reality technology. Combined with AR technology, a new method of clothing design visualization was proposed. The study innovatively applies AR technology to the field of clothing design and realizes the real-time virtual fitting effect. The experimental results prove that the method has a broad application prospect in the field of clothing design and e-commerce.

2.5. Cyclic autoencoder

Deng Zhixiang [51] studied the low light image enhancement method based on Retinex theory. By improving the Retinex algorithm, the image quality in low-light environment is significantly improved. The method innovatively solves the over-enhancement problem in the traditional Retinex algorithm and realizes a more natural brightness enhancement effect. Experiments show that the method performs well in night scene enhancement.

Minqin Gao [52] proposed a low light image enhancement algorithm based on Retinex and HSV color space. The study achieved a more natural color enhancement effect by combining the color space transformation with Retinex theory. The method shows strong adaptability in dealing with images under different lighting conditions, and especially has obvious advantages in maintaining color realism. The experimental results prove the effectiveness of the method.

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Chi-Nan An et al [53] developed a low-light image enhancement algorithm that combines gray world and Retinex. By combining the advantages of the two classical methods, a better enhancement effect was obtained. The study innovatively solves the limitations of a single method and realizes a more comprehensive image quality enhancement. Experimental validation shows that the method can achieve stable results in various low-light scenes.

Vivian Shen et al [54] studied a low illumination image enhancement technique based on multi-scale gradient domain guided filtering. The edge information of the image is better preserved through gradient domain processing. The method pays special attention to detail retention and edge enhancement, which improves the overall image quality while avoiding excessive smoothing. The experimental results show that the detail preservation effect is good.

Mudeix et al [55] proposed an improved multi-scale apple surface defect detection method based on Retinex. The method was combined with a support vector machine classifier and achieved significant results in the field of agricultural product quality inspection. The study improved the accuracy of defect detection by optimizing the parameters of Retinex algorithm. Experiments prove that the method has important practical application value.

Yang Jianyong et al [56] developed an image enhancement based roadway defogging system. The system greatly improves the clarity of road images on foggy days through adaptive contrast adjustment and detail enhancement. The study innovatively solved the over-enhancement problem in the traditional fog removal algorithm and realized a more natural image restoration effect. Experimental validation shows that the system has important application value in real road monitoring.

Duan Tongyu [57] investigated a license plate recognition technique based on nighttime image enhancement. By improving the image quality under low illumination conditions at night, the accuracy of license plate recognition was significantly improved. The method focuses on local enhancement of the license plate region, which suppresses noise interference while maintaining character clarity. The experimental results demonstrate the usefulness of this technique in nighttime traffic monitoring.

Baoxiang Tang [58] proposed a new algorithm for low light image enhancement. The study achieves good results under different lighting conditions by designing an adaptive parameter adjustment strategy. The method innovatively combines local and global information to achieve a more balanced enhancement effect. Experiments show that the algorithm has strong adaptability and robustness.

Fu Chunbao [59] focused on low-light color image enhancement algorithms. A more natural enhancement effect was achieved by increasing the image brightness while maintaining the color information. The method pays special attention to color fidelity and innovatively designs a color balance mechanism, which effectively avoids the problem of bias in traditional methods. The experimental results show that the method has obvious advantages in color reproduction.

Shen Ruhan et al [60] proposed an image enhancement technique based on improved FA algorithm and incomplete Beta function. The enhancement effect was improved by optimizing the parameter adjustment strategy. In this study, the FA algorithm is innovatively combined with the Beta function to achieve more accurate image quality optimization. Experimental validation shows that the method performs well in complex scenes.

Wang Xiaoyuan [61] studied the implementation of image enhancement algorithm in low illumination. By optimizing the algorithm implementation, the processing efficiency and effect are improved. The method focuses on solving the efficiency problem in the practical application of the

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algorithm, and greatly reduces the computational complexity while ensuring the enhancement effect. The experimental results prove the practical value of the method.

Chen Bo et al [62] explored image enhancement and steel surface defect detection based on noise estimation. By combining noise reduction and enhancement, the accuracy of industrial detection was improved. The method innovatively combines noise estimation with image enhancement to achieve more accurate defect detection. Experiments show that the technique has important application prospects in industrial quality control.

3. A neural network-free approach

Deep Reinforcement Learning (DRL) has emerged as a powerful technique for solving complex sequential decision-making problems and has been widely used in character action synthesis. Compared with traditional deep learning methods, DRL enables characters to learn from their interactions with the environment and adjust their behaviors accordingly, resulting in more robust and dynamic characters.

DeepMimic, proposed by Peng et al. is a notable example of applying DRL to character motion synthesis. The framework utilizes deep reinforcement learning to mimic complex human movements from motion capture data while allowing characters to adapt to different environments and tasks.DeepMimic selects the most appropriate motion segments for a given situation and seamlessly switches between segments when necessary. DeepMimic can be easily applied to non-bipedal characters and shows a significantly higher dimensional movement space than other approaches. In addition, DeepMimic exhibits robustness to external perturbations and is able to generate plausible recovery actions when the character encounters unexpected disturbances. However, a notable limitation of DeepMimic is that the learning process is time-consuming, with each skill often taking several days to achieve satisfactory results.

Li Shujiang et al [63] investigated image enhancement techniques in complex scenes. The robustness of the enhancement algorithm in different scenes was improved by introducing an adaptive parameter adjustment mechanism. The method can automatically adjust the processing parameters according to the scene characteristics to realize more intelligent image enhancement. Experimental validation shows that the method has good scene adaptability.

Feifei Wang et al [64] proposed a low illumination target detection algorithm based on image adaptive enhancement. The robustness of the detection system was improved by the scene adaptive enhancement strategy. The study innovatively combines image enhancement with the target detection task, which significantly improves the detection performance in low illumination environments. Experimental results demonstrate the effectiveness of the method.

Yulong Huang et al [65] developed a low illumination target detection algorithm based on image feature enhancement. Feature enhancement improves the accuracy of target detection in low illumination environments. The method focuses on feature extraction and enhancement, which improves the real-time performance of the system while ensuring the detection accuracy. Experiments show that the technique has important practical application value.

Sun Zizheng [66] proposed an unsupervised scene adaptive image enhancement method. By designing an unsupervised learning framework, automatic adaptation to different scenes was realized. The study innovatively solves the problem that traditional methods require a large amount of labeled data and shows strong flexibility in practical applications. Experimental results demonstrate that the method has good generalization ability.

Dandan Gao [67] studied image enhancement techniques for archive digitization. Considering the special characteristics of archival documents, a specialized enhancement algorithm was developed.

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The method pays special attention to the clarity of text and the preservation of paper features, which improves the image quality while ensuring the accuracy of historical information. Experimental verification shows that this technology has important application value in the field of archive digitization.

Funasaka K et al [68] developed an adaptive algorithm for medical image enhancement. By analyzing the characteristics of medical images, a targeted processing scheme was proposed. The study focused on solving the problems of insufficient contrast and loss of details in medical images, providing more reliable image support for clinical diagnosis. Experimental results show that the method has significant advantages in medical image processing.

Murakami D et al [69] proposed a deep learning based image enhancement method for medical diagnosis. More accurate image optimization was achieved by incorporating clinical diagnostic requirements. The method innovatively incorporates medical expert knowledge into the enhancement algorithm, which significantly improves the visibility of diagnosis-related features. Experiments have demonstrated that this technique is helpful in improving diagnostic accuracy.

Li Guixiao [70] investigated image enhancement and detection techniques for cable tunnels. The accuracy of equipment detection was improved by improving the image quality in the tunnel environment. The method is specialized in developing an adaptive enhancement strategy for special lighting conditions in tunnel environments. The experimental results show that the technique has a promising application in industrial facility detection.

Chentanez et al [71] proposed a physically-based motion capture imitation framework that utilizes DRL to synthesize dynamically feasible and visually realistic actions. The method mimics unseen action segments and incorporates a novel action space consisting of joint torques and PD controller gains, allowing it to handle more complex dynamic actions. In addition, it incorporates mechanisms to recover from large disturbances and can immediately reset dead agents to avoid stagnation. However, this approach sometimes produces jittery movements, especially when the agent tries to optimize for more rewards by performing tiny movements. Additionally, due to the inherent challenge of striking a balance between mimicking segments of motion and meeting physical constraints, the method may have difficulty accurately tracking certain types of motion, such as flips.

Deep Q Learning (DQL) is another reinforcement learning technique that has been applied to character action synthesis. It aims to learn a strategy to map states to actions in a way that maximizes the expected cumulative reward.

Won et al [72] proposed a hybrid approach combining covariance matrix-adaptive evolutionary strategies (CMA-ES) with DQL for character movement synthesis. Compared to standard DQL, the method converges faster, finds better control strategies that result in flexible movements, and can be easily extended to other types of motions. By utilizing CMA-ES, the method can efficiently explore the parameter space and identify promising directions for strategy improvement. With the help of neural networks, switching between motor skills becomes instant and easy, allowing characters to adapt to different tasks and environments. However, the quality of simulated motor skills depends heavily on the initial reference trajectory, and insufficient keyframes can lead to unrealistic movements.

In addition to DRL and DQL, researchers have explored other deep learning variants for character action synthesis without explicitly using neural networks.

Yu et al [73] demonstrated the effectiveness of course-based learning in improving data efficiency and learning speed for character movement synthesis. By introducing courses that gradually increase the complexity of the task, the model can learn gaits that are appropriate for the

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speed, showing superior performance compared to methods that are not based on courses. However, the quality of the synthesized movements is still not comparable to methods that utilize real-world motion capture data.

Rajamäki and Hämäläinen [74] proposed a sampling-based model predictive control method that combines fast but imprecise nearest neighbor learning with slow but precise neural network training. This approach allows characters to act immediately and learn from experience, requiring no training data other than that generated through simulation. It produces stable motion with a small sampling budget, making it suitable for real-time or near real-time applications.

In conclusion, methods without neural networks, especially those based on deep reinforcement learning and its variants, show great potential for synthesizing realistic and dynamic character actions. Although these methods may require longer training times or struggle with specific types of actions, their ability to adapt to different environments and tasks makes them invaluable tools for creating immersive and interactive virtual experiences.

4. Comparison table

Table 1. Comparison table

Method category	Secondary methodological categories	Methodologies	Dominance	Limitations
Neural network based approach	Recurrent Neural Network (RNN)	Autoregressive RNN	Integrated with multi-scale feature extraction and attention mechanisms, it demonstrates superior performance in addressing image quality degradation in complex environments, effectively preserving image details and enhancing overall visual quality. Research applications in urban building image analysis, underwater image processing, industrial defect detection, and low-light image enhancement have shown significant improvements in detection accuracy, image clarity, and color reproduction.	In specific scenarios such as strong electromagnetic interference and extreme temperature environments, physical deviations can cause errors in image feature extraction and restoration, affecting the reliability of the results;And because the architectural design focuses on sequence modeling and lacks multi-button framework control, it is difficult to flexibly adapt to complex scenarios that require the collaboration of multiple interaction commands, limiting the expansion of the application
	Recurrent Neural Network (RNN)	Recurrent transition network	Specifically adapted for handling character movements on uneven terrains, it generates terrain-adaptive character motions in complex gaming and virtual reality scenarios, significantly enhancing immersion and realism.	Displays suboptimal performance in extreme terrain transformations or unknown environmental conditions.
	Convolutional Neural Network (CNN)	Multiple CNN-based image enhancement methods (e.g., EnlightenGAN, CycleGAN)	Demonstrates remarkable efficacy in low-light image enhancement, underground low-light image processing, water level sensor image enhancement, and industrial inspection image enhancement. It improves image brightness, maintains naturalness, optimizes network structures, and enhances detection system accuracy and reliability. Feature-retention focused methods play a critical role in applications such as bird target detection, endoscopic image enhancement, and remote sensing image enhancement.	Exhibits potential performance degradation over extended operational periods.Long-term continuous operation may lead to the accumulation of small errors in the feature extraction and reconstruction process, gradually degrading the image recovery accuracy.High complexity network structures require a large amount of computing resources; Running on edge devices or systems with limited hardware capabilities may cause latency issues.

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Table 1. (continued)

	Generative Adversarial Networks (GANs)	Multiple GAN-based image enhancement and fusion methods (e.g., cross-modal image enhancement and fusion, infrared-visible image fusion)	Achieves outstanding performance in low-light cross-modal image enhancement, multi-modal image fusion, remote sensing image processing, 3D reconstruction image enhancement, and garment design image enhancement. It improves image quality, resolves information loss issues, enhances detection accuracy, and enables real-time virtual fitting functionalities.	Presents lower computational efficiency compared to other methodologies.The model training process is prone to pattern collapse, and the generated images have problems with single features and lack of diversity.Sensitive to training data distribution, unstable enhancement or fusion effect when data distribution varies widely.
	Auto Encoder	Periodic autoencoder	Retinex theory-based improved algorithms enhance low-light image quality and address traditional algorithm over-enhancement issues. Combined with color space conversion and other techniques, it achieves natural color enhancement. Various methods demonstrate significant application value in agricultural product quality detection, roadway defogging, license plate recognition, and industrial inspection by preserving details, enhancing edges, avoiding excessive smoothing, and improving overall image quality.	Potential limitations exist in the processing of associated control signals.The control signal transmission process is susceptible to environmental noise interference, triggering signal distortion, so that the algorithm of image enhancement parameters regulation deviation.And there are differences in the control signal protocols and formats output by different devices, requiring additional algorithm adaptation and increasing system complexity.
Non-neural network approach	Deep Reinforcement Learning (DRL)	DeepMimic	Capable of mimicking complex human movements from motion capture data, enabling character adaptation to diverse environments and tasks. It selects optimal motion segments for specific scenarios with seamless switching, exhibits robust resistance to external perturbations, and generates plausible recovery motions. Applicable to non-bipedal characters with a higher-dimensional movement space.	Requires a time-consuming learning process, with each skill typically demanding several days to achieve satisfactory results.
	Deep Reinforcement Learning (DRL)	Physics-based motion capture mimicry framework	Emulates unseen action sequences with novel action spaces for complex dynamic actions, incorporating disturbance recovery and dead agent reset mechanisms to prevent stagnation.	Produces jerky movements in certain scenarios. Struggles to balance motion segment mimicry with physical constraints, leading to difficulties in accurately tracking specific motion types (e.g., flips).
	Deep Q Learning (DQL)	DQL methodology integrated with CMA-ES	Achieves faster convergence than standard DQL, discovers optimal control strategies, and generates flexible movements scalable to various motion types. Neural network-assisted instant motor skill switching enables character adaptation to diverse tasks and environments.	Simulated motor skill quality is highly dependent on the initial reference trajectory. Insufficient keyframes result in unrealistic movements.
	Other deep learning variants	Course learning methods	Effectively improves data efficiency and learning speed in character movement synthesis, enabling the acquisition of speed-appropriate gaits.	Synthetic motion quality is inferior to methods utilizing real-world motion capture data.
	Other deep learning variants	Sampling-based model predictive control approach	Enables immediate character action and experience-based learning without relying on external training data (except simulation-generated data). Produces stable motions with minimal sampling budgets, making it suitable for real-time or near-real-time applications.	No explicit limitations documented in the current context.

5. Reach a verdict

This survey highlights the progress made in character action synthesis using deep learning techniques. Methods that incorporate neural networks (e.g., RNNs, LSTMs, CNNs, GANs, and autoencoders) have achieved promising results in generating realistic and complex character actions. However, these methods typically require large datasets and computational resources. Non-neural

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network methods, especially those based on deep reinforcement learning, have been shown to be adaptable to dynamic environments and continuous decision-making tasks. The future of character action synthesis lies in combining the strengths of different networks and learning strategies and integrating physically-based controllers to improve realism and quality.

This survey provides a comprehensive overview of the current state of the art in deep learning-based character motion synthesis techniques, contributing to further research and development in this exciting area.

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