Journal of Autonomous Intelligence (2024) Volume 7 Issue 5
doi: 10.32629/jai.v7i5.1661

ORIGINAL RESEARCH ARTICLE

Feature extraction of symbols in petroglyphs based on SIFT algorithm

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ABSTRACT

Currently, petroglyphs are facing various potential damages, especially the significant damage caused by weathering. To protect petroglyphs from damage, this article takes the petroglyph group in Helan Mountains as an example and collects them based on machine vision. They are divided into four categories based on character, animal, simple geometry, and religious symbols, and filtering is used to denoise and increase the collected images. Petroglyphs' features are extracted using the SIFT (scale-invariant feature transform) algorithm. The results show that the method proposed in this paper has a good extraction effect on the petroglyph features of Helan Mountains, with a recognition accuracy of over 95%, providing ideas for the protection of petroglyphs in Helan Mountains.

Keywords: petroglyph; machine vision; filtering enhancement; SIFT feature extraction

ARTICLE INFO

Received: 22 March 2024
Accepted: 7 April 2024
Available online: 12 August 2024

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1. Introduction

Petroglyph, as a carrier of stone, has rich expressive content and various forms of expression. It is an important component of Chinese culture and the crystallization of the wisdom and art of ancient Chinese people. At present, petroglyphs have been discovered in more than 20 provinces and cities in China, but the content reflected by them varies from place to place. Petroglyph has high historical, cultural, and artistic research value. Currently there is still a lack of depth and breadth in the research on petroglyphs in China. The research on their craftsmanship is still in its early stages, and a series of comprehensive studies on it are still blank.

Traditional algorithmic feature extraction methods have some disadvantages in processing petroglyph images relative to utilizing SIFT feature extraction methods. These include but are not limited to: the traditional algorithm is not robust to changes in illumination, scale, rotation, etc., and is susceptible to image noise and interference, the extracted features have limitations that make it difficult to meet the needs of complex images, and the algorithm is usually sensitive to the parameters, which need to be manually adjusted to adapt to different scenarios, so the performance of traditional algorithms when dealing with images with complex textures and structures such as petroglyphs may be limited.

This article takes the petroglyphs of Helan Mountains as the research object, and uses machine vision technology to classify different types of petroglyphs into four categories: character, animal, simple geometry, and religious symbols. Using the SIFT feature extraction method, feature extraction is performed on four types of petroglyph images. The degrees of damage of different types of petroglyphs are compared to validate that the proposed method is effective, providing a reference for the precise protection of petroglyphs in Helan Mountains and research in other areas.

2. Related work

Due to the preciousness and non-renewable nature of petroglyph, the carrier materials are extracted for research while ensuring the safety of its body. Zhang Yucheng took the petroglyphs in the Tongtian River basin as the research object and organized the discovered petroglyph spots based on archaeological investigation reports. He used the maximum entropy model to establish archaeological site prediction models for the overall and individual petroglyph groups in the Tongtian River basin. His research results showed that there were significant differences in the distribution characteristics of various petroglyph groups in the region, but there were similarities within the petroglyph groups[1]. To explore the cultural connotations and artistic characteristics of corner patterns in nomadic embroidery patterns, Jin combined traditional corner patterns with modern design and conducted in-depth research and analysis of the artistic characteristics of corner patterns from three aspects: Shape, composition, and color. He extracted graphic and color elements, simplified, decomposed and reconstructed them to obtain innovative graphics that integrate modern aesthetic concepts[2]. To solve the problem of reasonable and efficient identification of limestone with different degrees of dissolution in karst areas, scholars such as Zhang Yan constructed a convolutional neural network model for identifying limestone with different degrees of dissolution in the Qixing District of Guilin. His results showed that the CNN model has the highest prediction accuracy of 97.6%, providing a new approach for effectively identifying the degree of limestone dissolution in karst areas[3]. These technologies can achieve good results in identifying directions, but due to the vulnerability of petroglyphs, they are difficult to provide good protection.

Machine vision enables computers to obtain, process, and understand information from images or videos, achieving good extraction results in the direction of feature extraction[4]. The use of machine vision methods can perform non-destructive testing, avoiding the shortcomings of low efficiency and easy damage of traditional manual testing[5]. Dang Manyi used machine vision to quickly identify potato late blight. Based on the different characteristics of color, texture, and shape of potato leaf late blight, he established a mathematical model to evaluate the disease[6]. Tu proposed a quality detection method for peanut kernels based on machine vision and self-adaptive convolutional neural networks (CNN). His results indicated that the average accuracy of peanut detection in the target domain was 99.7%, which had higher convergence and accuracy compared with those of traditional CNN[7]. Hu, W detected cracks in road surfaces based on machine vision, and collected infrastructure inspection data through imaging equipment to identify the presence, location, and degree of cracks, and to classify the corresponding severity[8]. It can be found that machine vision can effectively avoid object damage while maintaining a high level of accuracy in feature extraction. Therefore, this article utilizes machine vision to extract and analyze the features of the symbols of the petroglyphs in Helan Mountains.

3. Method for feature extraction of symbols of petroglyphs

3.1. Data sources

This article is based on the petroglyph group of Helan Mountains. The petroglyph group of Helan Mountains is located at the foot of Helan Mountains, with geographical coordinates of 38°00′ N and 105°30′ E. Its distribution is shown in **Figure 1**. The Helan Mountains area has sedimentary rocks mainly composed of quartz and feldspar, which are considered an important carrier for the “World Cultural Heritage”—the petroglyph research of Helan Mountains in Ningxia. However, nowadays, due to weathering, the surface of petroglyphs on rocks and their shape contours are blurry, some of which are also about to disappear[9].

Figure 1. Petroglyph areas of Helan Mountains.

The Helan Mountain Petroglyph Complex may be considered a cultural heritage, and therefore national or local cultural heritage institutions may have relevant image data. The data sources for the experiments in this paper come from these cultural heritage organizations as well as rock images captured by cameras. The ratio of the training set to the test set is set to 8:2, the image pixels are 1920 × 1080, and there are 1223 sample images of different types. In order to prevent image damage to rock art images captured by cameras, when capturing rock art images with cameras, it is necessary to maintain an appropriate distance, avoid direct contact with the surface of the rock art, choose appropriate lighting conditions and limit the duration of the shooting, avoid the use of flash as much as possible, consider the use of filters to minimize the impact of harmful light on the rock art and comply with the relevant rules and regulations to ensure that the potential damage to the rock art is minimized.

The petroglyph of Helan Mountains is the most important remains of petroglyph in China, playing an irreplaceable role in the development of ancient Chinese civilization and human society. The content of petroglyph includes characters, animals, and life scenes, which is rich and diverse, depicting the production, life, and religious beliefs of the ancestors. Although these petroglyphs are well preserved, they are threatened by both natural erosion and human activities. To avoid disrupting the petroglyph group, cameras are used to capture the images. The petroglyph group is mainly divided into four categories: character petroglyphs, animal petroglyphs, geometric symbols and abstract patterns, and religious petroglyphs. Some datasets are shown in **Figure 2**.

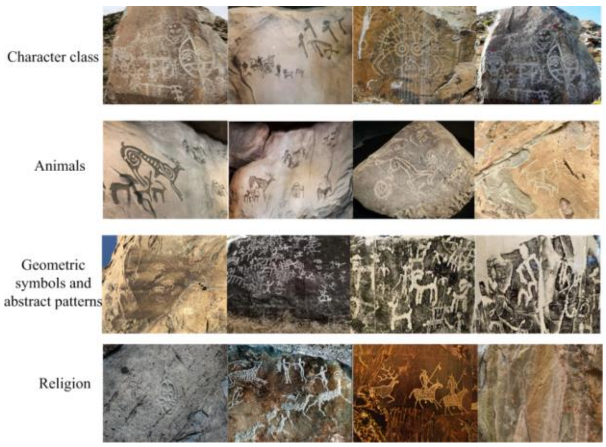

Figure 2. Some petroglyph sets.

The surface layer of rock mass in Helankou is prone to chalking, peeling, and diseases, especially rock masses represented by human face portraits, facial masks, animals, hand prints, etc. Under the influence of the cycle of freezing and thawing, water-salt damage, and periodic temperature and humidity, the mud impurities, calcium, and siliceous cements in these rock masses undergo dissolution and loss, resulting in a decrease in cohesion between them and a large area of granular loose detachment. The surface of the rock is also relatively rough, and obvious particles can be felt when touched by hand.

3.2. Image denoising and enhancement

Noise reduction processing of images usually uses filtering algorithms, and the steps include loading the image, gray scale conversion (if it is a color image), selecting the appropriate filter, setting the filter parameters, applying the filter, boundary processing (optional), adjusting the filter result (optional), and finally saving the processed image. Different filter and parameter choices will produce different noise reduction effects, so it may be necessary to try several methods to find the best processing, the detailed steps are shown in **Figure 3**.

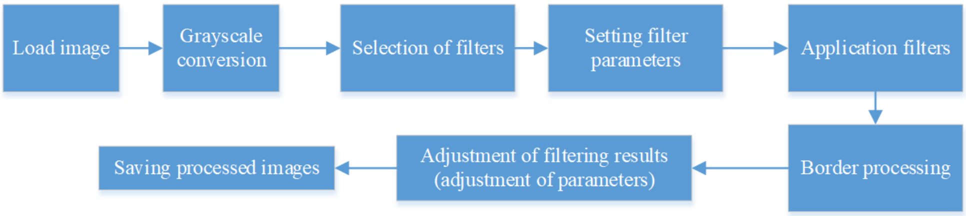

Figure 3. Noise reduction and smoothing steps of image processing.

Due to factors such as the acquisition device and transmission environment, the images contain a large number of false corners. If corner points are directly detected, it has an adverse impact on images' quality, and noise reduction processing is required for the images. The images are smoothed using a filtering algorithm. The effect of denoising using median filtering is shown in **Figure 4**.

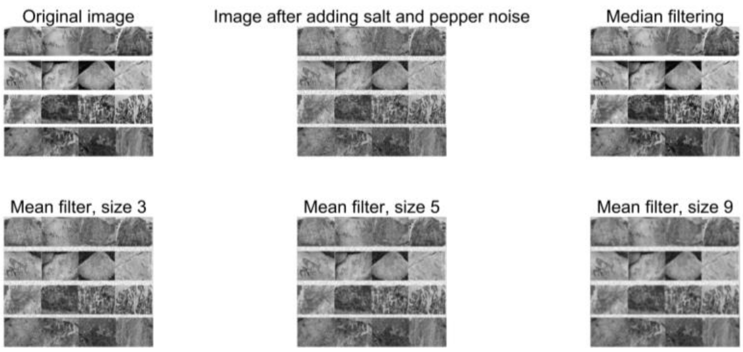

Figure 4. Effect after denoising.

3% salt and pepper noise are added to the original images. After the initial denoising with a 3 × 3 module of median filter, white and black spots in the interfering image can be removed, but compared with the original image, the image is still a bit blurry. The main reason is that during filtering, regardless of whether the pixel is contaminated or not, it is replaced by the median, resulting in some parts of the image still blurring. If further sharpening is possible, the effect can be better.

On this basis, a wavelet decomposition method based on wavelet transform is proposed, which has important application value in wavelet transform. When the variance is too large, the information content of the image can be lost, so while removing noise, it is important to preserve the original details of the image as much as possible[10,11].

3.3. Feature extraction

This article uses the SIFT algorithm to extract the features of petroglyphs. The SIFT algorithm is a target recognition algorithm based on image feature point matching[12]. The SIFT algorithm can extract feature points of an image to detect and describe local features of the image. It has good robustness, scale invariance, and rotation invariance, and is suitable for identifying targets such as petroglyphs that have rich shape features but not obvious color features[11–13].

To improve the accuracy of feature points, it is necessary to remove edge points and low contrast points from the selected candidate points. Then, the remaining points are assigned information such as position, scale, and principal curvature to increase the stability of feature point matching, in order to allocate the direction of the next extreme point. Due to the fact that the image is a discrete signal, it is necessary to correct the extreme points[14]. The Difference of Gaussians (DOG) function has poor edge response in images, so in order to further improve the stability of extreme points, it is necessary to eliminate the influence of edge response[15]. By estimating the second-order Hessian matrix of this point, Equation (1) can be obtained:

$$H = \begin{bmatrix} D_{xx} & D_{xy} \\ D_{yx} & D_{yy} \end{bmatrix} \tag{1}$$

If the maximum and minimum eigenvalues of H are α and β respectively, then there are:

$$Tr(H) = D_{xx} + D_{yy} = \alpha + \beta \tag{2}$$

$$Det(H) = D_{xx}D_{yy} - D_{xy}D_{yx} = \alpha\beta \tag{3}$$

Assuming $\alpha = r\beta$, if Equation (4) is met, then the extreme point is retained, otherwise the extreme point is deleted:

$$\frac{Tr(H)^2}{Det(H)} < \frac{(r+1)^2}{r} \tag{4}$$

To select the extreme points of the DOG function, each pixel should be compared with all its neighboring points. After the comparison is completed, the pixels that meet the maximum or minimum grayscale values within the current range are recorded. The image extracted using SIFT features is shown in **Figure 5**.

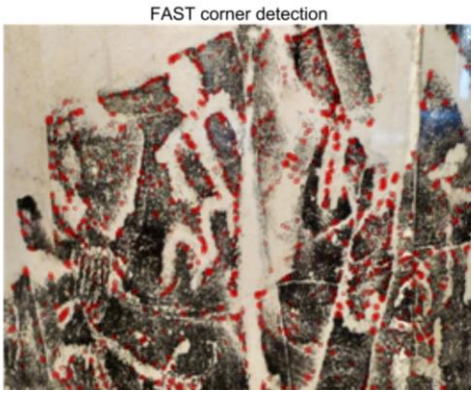

Figure 5. Results of feature extraction.

The SIFT features of each sub frequency image in multi-scale space are obtained, and the SIFT features of each sub frequency image are extracted. Each sub frequency of each sub frequency image is classified separately[16–18]., and finally a multi classifier synthesis method is used to discriminate and fuse them[19–21].

4. Experiment and discussion

4.1. Effect of feature extraction

To better evaluate the robustness and accuracy of the model, the accuracy, precision, recall, and F1 values are used as evaluation criteria in the experiment to test the effectiveness of feature extraction under the proposed algorithm. The obtained results are shown in **Figure 5**.

From **Figure 6**, it can be seen that after testing different types of petroglyphs, the algorithm in this paper has the highest accuracy in recognizing simple geometric symbols. However, when recognizing religious petroglyphs with more complex patterns, the recognition effect is lower compared with that of other patterns[22–24], with the recognition accuracy around 95%. This is due to the significant changes in religion over time[25–27], resulting in significant changes in religious patterns compared to before. Therefore, the results of feature extraction have a lower recognition rate compared with those of other characters, animals, etc.

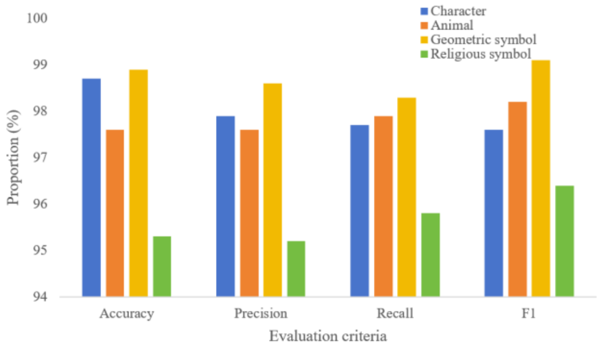

Figure 6. Test results.

From the experimental results in **Table 1**, it can be concluded that the SIFT algorithm performs the best in terms of matching accuracy and recall, but is slightly slower. The SURF algorithm is slightly better than SIFT in terms of matching speed, but is slightly lower in terms of accuracy and recall. The ORB(Oriented FAST and Rotated BRIEF) and BRISK(Binary Robust Invariant Scalable Keypoints) algorithms are the fastest but slightly inferior to SIFT and SURF (Speeded Up Robust Features) in terms of accuracy and recall. Therefore, although the SIFT algorithm may not be as fast as the other algorithms, it performs better in terms of matching accuracy and recall, proving the sophistication of the SIFT algorithm.

Table 1. Comparative analysis of different algorithms.

Algorithm	**Matching accuracy**	**Matching recall**	**Matching speed**
SIFT	0.85	0.9	100 ms
SURF	0.78	0.85	80 ms
ORB	0.7	0.75	50 ms
BRISK	0.72	0.8	60 ms

4.2. Identification of petroglyph damage

After feature extraction of petroglyphs, feature recognition is mainly used to identify the damage of petroglyphs, in order to achieve better protection for the petroglyphs in Helan Mountains. The identification effect of damage is shown in **Figure 7**:

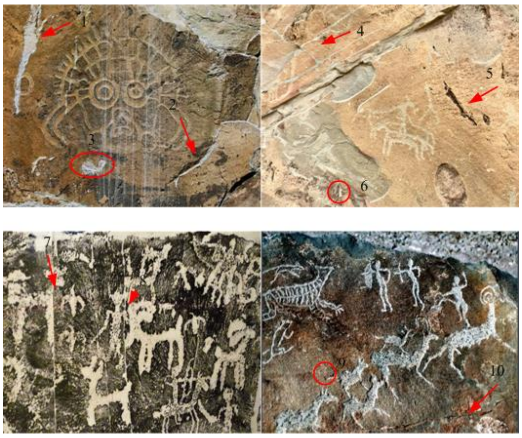

Figure 7. Identification effect of damage.

From **Figure 7**, it can be seen that the damage to the petroglyph in Helan Mountains is mainly caused by natural weathering of the rock, and other activities such as tourist activities, quarrying, and development can also cause damage to the petroglyph. To protect petroglyphs, it is necessary to comprehensively[28–30] consider these potential destructive factors and take corresponding protective measures, including establishing protection zones, restricting tourist activities[31–33], conducting scientific restoration and maintenance, etc.

5. Conclusion

Petroglyph is a means used by primitive people to express emotions. Thanks to its excellent creative text design, even thousands of years have passed, the charm of petroglyph continues to present different flavors to people, becoming a unique landscape. The story of petroglyph is a regional culture that reflects the religious customs of primitive ancestors. This article takes the petroglyph of Helan Mountains as the research object, and uses machine vision technology to obtain data on the petroglyph of Helan Mountains. This article also utilizes a series of algorithms to preprocess and extract its features. The causes of the destruction of the petroglyph in Helan Mountains are then clarified, thus providing a theoretical basis for the reasonable protection of the petroglyph in Helan Mountains. However, there are limitations to the technique of extracting petroglyph features using the SIFT algorithm, which may not be sensitive enough to specific textures, shapes and structures in the petroglyph images, resulting in insufficient features to fully characterize the complex information of the petroglyphs, especially in the case of petroglyphs subject to severe wear and tear or unsatisfactory lighting conditions, the features extracted by the SIFT algorithm may be affected, which restricts its application in the petroglyph research and conservation. The application of SIFT algorithm in rock painting research and conservation is limited.

Author contributions

writing—original draft preparation, HH; writing—review and editing, BB; supervision, PP; All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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