ZIBELINE INTERNATIONAL™ PUBLISHING

JOURNAL OF ROCK ART (JRA)

E-ISSN: 2976-2421 (Online)
CODEN: JRAOCQ

***DOI:** http://doi.org/10.65098/jra.01.2024.20.26*

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REVIEW ARTICLE

ANALYSIS OF SIMILARITY AND IMAGE RECOGNITION OF HUMAN FACE ROCK ARTS IN HELAN MOUNTAIN

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ARTICLE DETAILS

Article History:

Received 9 January 2024
Accepted 15 February 2024
Available online 20 March 2024

ABSTRACT

The Helan Mountain region boasts a diverse array of Human Face rock arts, serving as a vital cultural heritage resource in China with significant research value. However, large-scale comparative and identification studies of numerous human-faced rock arts typically require the involvement of specialized researchers and substantial time and effort. This study aims to take advantage of image processing techniques from the field of computer science to analyze Human Face rock arts in the Helan Mountain region, facilitating a more rapid and accurate comparison and identification of these precious rock arts. The research findings indicate that image similarity calculation methods can effectively capture the degree of similarity among Human Face rock arts. Additionally, image recognition methods based on deep learning exhibit the capability to swiftly identify Human Face rock arts. Both approaches demonstrate practical utility in the study of Human Face rock arts.

KEYWORDS

Human Face rock arts, Image recognition, Digital humanities

1. INTRODUTION

Rock art is a cultural form in which ancient ancestors depicted their lives and expressed themselves (Shu, 2007). In China, Human Face rock arts are exquisitely crafted and feature unique images and rich content. They are distributed across multiple provinces and form an independent system, with three major distribution belts within China. Helan Mountain is one of the areas in China with a concentrated distribution of rock art, as well as the region with the largest number of Human Face rock arts images. Helanshan rock art are of enormous scale, and have caused a stir in the international rock art community since their discovery in the last century. Thousands of rock art have been investigated by experts and Human Face rock art are distributed among all fifteen rock art sites on Helan Mountain (Gou, 2017).

A large number of Human Face rock arts are concentrated in the Helan Mountain region, forming a distinctive style. But with the passage of time, Human Face rock arts created on natural rock surfaces in the Helan Mountain region face various physical and chemical threats, including weathering and erosion from factors such as wind and salt. In order to better preserve these rock arts and thoroughly explore the cultural significance embedded within them, we employ deep learning methods for rock art classification and detection recognition. This approach facilitates researchers in rapidly accomplishing fundamental classification and identification while also assisting rock art enthusiasts in independently learning and exploring the mysteries of rock art.

Image recognition is one of the key challenges in the field of computer science. With the rise of deep learning, significant progress has been made in automated image recognition, finding widespread applications in various domains such as medical image analysis, autonomous driving, video surveillance, and more. The advent of artificial intelligence has sparked enthusiasm across industries, and the realm of rock art is no exception. Scholars both domestically and internationally have started employing methods like object detection and transfer learning to study the localization and classification of rock art, achieving noteworthy results.

2. RELATED WORK

In the field of computer science, image recognition stands out as a key challenge. With the rise of deep learning, significant progress has been made in automated image recognition, finding widespread applications in various domains such as medical image analysis, autonomous driving, and video surveillance. The advent of artificial intelligence has triggered enthusiasm across industries, and the domain of rock art is no exception. Scholars both domestically and internationally have initiated research

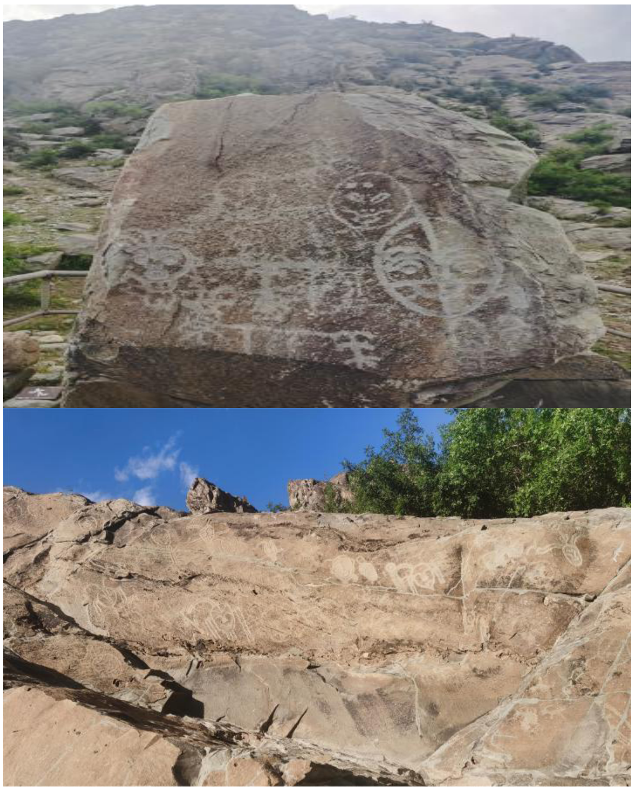


Figure 1: Human Face rock arts in Helan Mountain

(Taken by the author in the Helan Mountain region)

on the localization and classification of rock art using methods like object detection and transfer learning, achieving notable results.

In 2020, the rock art research team from the University of Ioannina in Greece conducted experiments with two methods for the automatic detection of three rock art sites (Tsigkas et al., 2020). They found that the use of YOLOv2 deep learning outperformed the SIFT and random sample consensus methods. Their conclusion was that, for rock art detection, the image background was more useful than the rock art itself.

In Australia (2021), researchers including Andrea Jalandoni and Yishuo Zhang employed deep learning methods to detect the presence of rock art in rock images (Jalandoni et al., 2022). This served as confirmation that machine learning approaches are viable for rock art applications, encouraging further exploration of the potential of artificial intelligence methods in rock art research. In addition, Jarrad Kowlessar (Kowlessar et al. 2021) and other researchers classified Australian Arnhem rock art styles using a dataset of 98 rock art images along with trained models like AlexNet, VGG, and ResNET. Using the learned features, they attempted to construct a chronological style timeline for rock art.In Sweden, Horn(Horn et al., 2021) and other researchers created a model to locate and classify images from Swedish rock art. They trained the model using faster R-CNN, data augmentation, and transfer learning from images generated from 3D scans.

Compared to foreign countries, China's digital humanities practice primarily focuses on data management and digitization, which includes the construction of various databases containing digital photos of rock art, line drawings, rubbings, and related materials. However, most scholars have not fully leveraged these rock art databases, and research based on these databases often lacks sustainable directions (Shu et al., 2022). And only a few scholars have used deep learning methods to study rock art in recent years. Researchers led by Li Chunshu at Ningxia University, capitalizing on their unique geographical advantage and using the Helan Mountain rock art as their material, conducted studies in target detection and recognition (Jia et al., 2022), as well as semantic recognition of rock art (Wu 2022), using deep learning methods. Their work has contributed valuable experience and knowledge to the development of this field in our country. Overall, there is still considerable room for improvement in domestic research compared to international standards.

This study focuses on the Human Face rock arts in the Helan Mountains as the primary experimental subject. Given the unique structural characteristics of rock art materials and the variability in rock art features, we selected the grayscale histogram algorithm and perceptual hash algorithm to calculate image similarity. Additionally, the SIFT algorithm was employed to extract key points of the Human Face rock arts. We also opted for the YOLO target detection model, suitable for this research, in an attempt to achieve preliminary recognition of Human Face rock arts in the Helan Mountains.

3. ANALYSIS OF IMAGE SIMILARITY FOR HUMAN FACE ROCK ARTS

3.1 Basic Features and Classification of Human Face Rock Arts

Before delving into the exploration of similarity analysis and recognition pathways for Human Face rock arts in the Helan Mountains, a fundamental understanding of their types is essential. Human Face rock arts exhibit diverse types, primarily characterized by their resemblance to human faces or the presence of facial and head features such as facial features, necks, facial adornments, or headgear. In the process of rock art image comparison and recognition, computers primarily analyze the external appearance of the rock art.

By directly observing the external visual characteristics of Human Face rock arts in the Helan Mountains, this study identifies four relatively common types. The first type is characterized by a prominent linear square outline with facial features. Both depicted images have facial features, and there may be decorations on the forehead and face, possibly representing religious or ritualistic mask attire. This type emphasizes the clarity of overall shape and outline. The second type features rock art with headgear. Images show distinct headgear shapes and patterns above the faces, indicating varying statuses and identities of individuals.

The third type emphasizes the depiction of eyes, with oval external outlines and circular patterns representing eyes. These abstract depictions, particularly focusing on eyes, may reflect ancient eye worship. The fourth type highlights distinct depictions of teeth, often using vertical lines to represent teeth. These images, depicting open mouths with exposed teeth, convey a strong sense of awe and might symbolize worship of health and robust vitality in ancient times.

3.2 Comparison and Similarity Analysis of Human Face Rock Arts Images

The comparison and similarity analysis of Human Face rock art images involve the digitization of these images. Subsequently, the obtained digital representations are utilized to analyze different Human Face rock art through computer-calculated similarity metrics. Similarity calculation plays a crucial role in the domain of image comparison and recognition, and in the case of Human Face rock art, this involves assessing the similarity of images in a rock art database. Given the common types of Human Face rock art images, including colored monolithic rock art and black-and-white line drawings, we employ two similarity calculation algorithms—grayscale histogram and perceptual hashing. Additionally, we utilize the Scale-Invariant Feature Transform (SIFT) algorithm for extracting and matching key features of Human Face rock art images, aiming for a more precise exploration of the features and connections between rock art images.

The grayscale histogram algorithm is a classical method for calculating image similarity. It assesses the similarity of images by comparing their grayscale level distributions. In the context of Human Face rock art, the grayscale histogram algorithm helps capture key features related to color and brightness variations, enabling quantitative analysis of similarity between images. The perceptual hashing algorithm is a similarity calculation method based on the perceptual features of images. It simulates the way the human visual system perceives images by extracting high-frequency and low-frequency information to determine the image's hash value. This algorithm is particularly useful for handling Human Face rock art images under different lighting conditions, as it

Table 1: Human Face rock arts with different features in Helan Mountain region

(Sourced from 'Rock Arts of the Helan Mountains', volume 1, compiled by the Second Northwest University for Nationalities)

Main Features	Line Drawings	
Square Outline		
Wearing Crown		
Prominent Eyes		
Depicting Teeth		

mitigates the impact of lighting changes on similarity analysis.

The Scale-Invariant Feature Transform (SIFT) algorithm is employed in the process of similarity calculation. The steps include building a scale space, detecting local extrema, finding key feature points, locating key points, assigning directions, describing feature points, and matching feature vectors (Wang et al., 2019). SIFT is a widely used feature extraction and matching method in the field of computer vision. It detects key points in an image and describes their local features, facilitating similarity calculations between different images. For complex images like Human Face rock art, the SIFT algorithm can capture unique texture and structural information in the rock art, contributing to a more accurate similarity analysis.

These three similarity calculation algorithms have distinct principles and advantages. In practical applications, due to the diversity of Human Face rock art images and the differences in algorithm principles, there may be variations in similarity calculation results. Therefore, in the process of similarity comparison calculations, a series of reasonable steps are necessary to ensure the accuracy and reliability of the results. Firstly, to eliminate the influence of irrelevant elements in the images on similarity calculations, it is common to preprocess the images by removing background noise, adjusting lighting, and color balance. Such preprocessing enhances the precision of similarity calculations, focusing on the intrinsic features of the rock art itself. Secondly, given the diverse principles and characteristics of different algorithms, it is often advisable to employ multiple suitable algorithms for similarity calculations. This approach contributes to obtaining more comprehensive results in different situations and reduces calculation errors. Typically, the similarity calculation results from various algorithms are averaged to derive the final similarity assessment.

3.3 Case Study

Next, we illustrate the above process with a specific case study. To evaluate the similarity under different angles and lighting conditions, two images of Helanshan Sun God rock art from different publications were selected. Firstly, we employed perceptual hash algorithm and grayscale histogram algorithm for similarity calculation on these two images. The results showed similarity scores of 71.86% and 67.03% for the two algorithms, respectively. This indicates a general structural similarity between the two Sun God rock art images, with some differences noted, particularly in the completeness of the left image, likely attributed to sampling variations by researchers at different times.

To gain a more detailed understanding of their similarities and differences, we utilized the Scale-Invariant Feature Transform (SIFT) algorithm to showcase the connecting lines between these feature points. This approach highlights both similarities and distinctions among these points, enabling a deeper exploration of the image details and a more comprehensive analysis of their relationships. These three methods offer new tools for in-depth studies of human-faced rock art, aiding in a better comprehension of its characteristics and historical context.In the future, with sufficient data, establishing a rock art image comparative system could be viable. This system would incorporate rock art information from different regions and, through similarity calculations, enable the computer to provide a series of highly similar rock art images. This would facilitate further analysis by researchers on the structural features of these images.

4. THE RECOGNITION PATH OF HUMAN FACE ROCK ART IMAGES

With the guidance of modern technology, particularly the groundbreaking advancements in deep learning and computer vision, we have the opportunity to analyze, recognize, and preserve these precious rock art images from an entirely new perspective. This study focuses on the exploration of the recognition path for Human Face rock art images. By

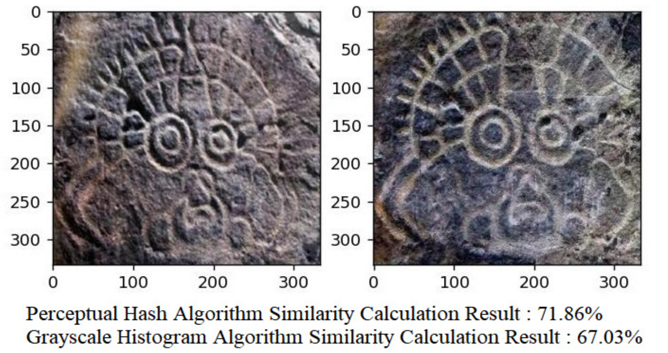


Figure 2: Perceptual hashing algorithm and gray histogram algorithm calculation results

(The image on the left is sourced from “Helanshan Rock Art 1” compiled by Northwest Second Nationalities Institute, and the image on the right is referenced by the author from “Discovering Rock Art” by Li Xiangshi)

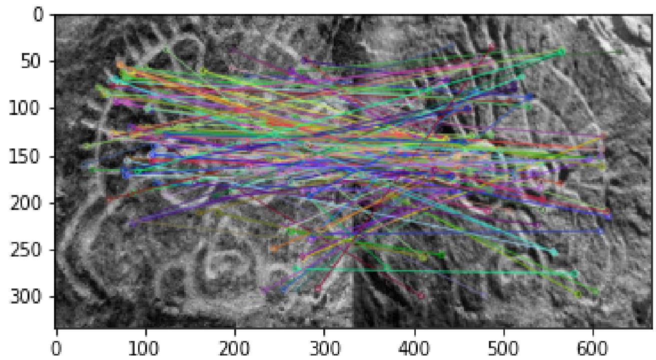
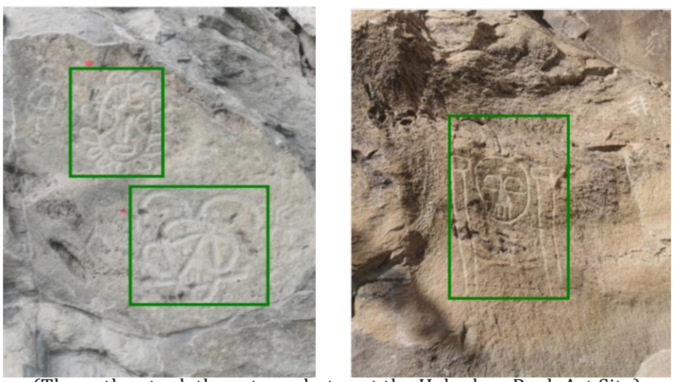


Figure 3: Implementing image feature point matching using SIFT algorithm

integrating deep learning techniques and image processing methods, we aim to automate the identification of Helanshan Human Face rock arts, offering a more profound understanding of the historical, cultural, and artistic context of these rock paintings. This section will provide a detailed overview of the research methods and case analyses.

4.1 Digital Recognition Process of Human Face Rock Arts

preliminary identification process aids in determining whether an image encompasses Human Face rock art. Upon confirming the presence



(The author took these two photos at the Helankou Rock Art Site)

Figure 4: The positioning of the Human Face rock arts in the picture

The key of digitized recognition of Human Face rock art lies in pinpointing the locations of such depictions and extracting their primary features. Initially, we analyze rock art images or line drawings to ascertain the presence of facial contours or features resembling a human face. This

of Human Face rock art, a more precise localization of each facial depiction is performed. Utilizing rectangular bounding boxes, we mark and highlight the position of each human face within the rock art image.

Due to the diversity and variations in Human Face rock art, compounded by the influence of natural factors such as weathering and rain erosion, their image representations become intricate and abstract, replete with numerous nonlinear elements. This complexity poses higher demands on the model’s performance. Deep Convolutional Neural Network models, as powerful tools for nonlinear modeling, exhibit unique advantages in the analysis and processing of image data. The hierarchical structure of deep learning, encompassing low-level simple features and high-level abstract features (Zhang et al., 2017), allows for a more comprehensive expression of complex Human Face rock art images.

Therefore, we opt for the utilization of a deep convolutional neural network, coupled with the widely applied YOLO series of object detection algorithms. This combination enables the computer to achieve superior training results when handling diverse, feature-rich, and highly abstract Human Face rock art images. The construction steps of the entire recognition model are illustrated in the figure below. Each part will be detailed in the following sections.

4.2 Prepare the Dataset

In this study, Human Face rock art image data primarily originated from the “Northern China Rock Art Database” and the extensive series of books “Helanshan Rock Art (Volumes 1–3)” (Northwest Second Ethnic Institute Compilation., 2007), ensuring the reliability and diversity of the dataset. Subsequently, the collected images underwent preliminary screening to remove poor-quality or unrelated images to Human Face rock art. To acquire detailed information about the location and features of the Human Face rock art targets in the images, the Labelme tool was employed for comprehensive annotation of each image, as shown in the figure below.

Simultaneously, to enhance the diversity of the dataset and utilize the data fully, preventing overfitting due to insufficient data, data augmentation operations were performed, including cropping, flipping, and padding. This aids in improving the model’s generalization capability. Finally, the dataset was randomly divided into training, validation, and test sets in a 6:2:2 ratio, facilitating model training, tuning, and evaluation.

4.3 Experimental Environment and Training Parameter Settings

In this study, we employed the YOLOv5 algorithm for the recognition of Human Face rock art. To ensure experiment accuracy and reproducibility, we conducted detailed experiment environment configuration and training settings. Firstly, the CPU used was an 11th Gen Intel(R) Core (TM) i7-11800H, possessing 16-core processing capability and 128GB of memory, supporting large-scale data processing and deep learning model training. The GPU was an NVIDIA 3050 with 10GB of VRAM. The experimental operating system selected was Windows 10. In the realm of deep learning, we utilized PyTorch 1.7.1 as the primary deep learning framework, combined with CUDA 11.1 and CuDNN 8.0.5.39 for accelerated computation, optimizing model training performance. The compilation was carried out using Python 3.9.7.

The experiment employed the stochastic gradient descent (SGD) method for network training. The initial learning rate was set to 0.01, with 150 training epochs, a learning rate decay rate of 0.0001, input image size of 128, rectangular training, and the selection of the SGD optimizer, among other settings. This carefully configured experimental environment and training setup aimed to ensure that our deep learning model achieves optimal performance in recognizing Human Face rock art and provides a solid foundation for the reproducibility of the experiment.

4.4 Result and Analysis

As shown in Figure 8, the preliminary results of the experiment indicate that the model has certain effectiveness in recognizing Human Face rock art. It can successfully detect the majority of Human Face rock art in digital images, achieving an accuracy rate of over 70% in the test set. This

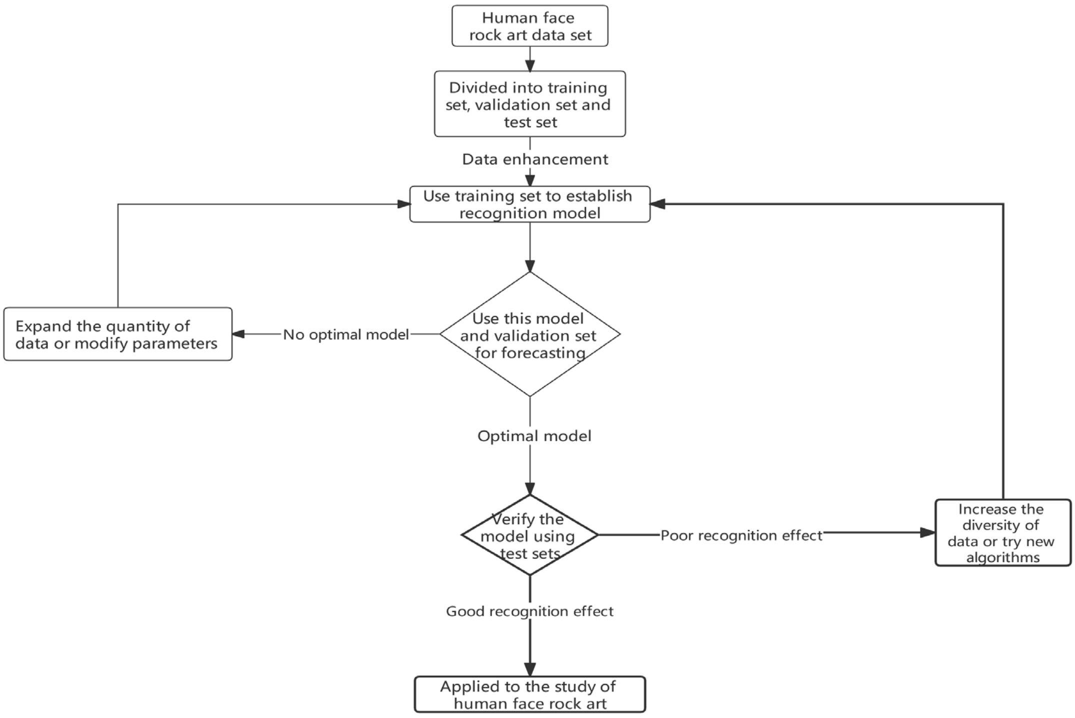


Figure 5: A simplified flowchart for Human Face rock arts image recognition

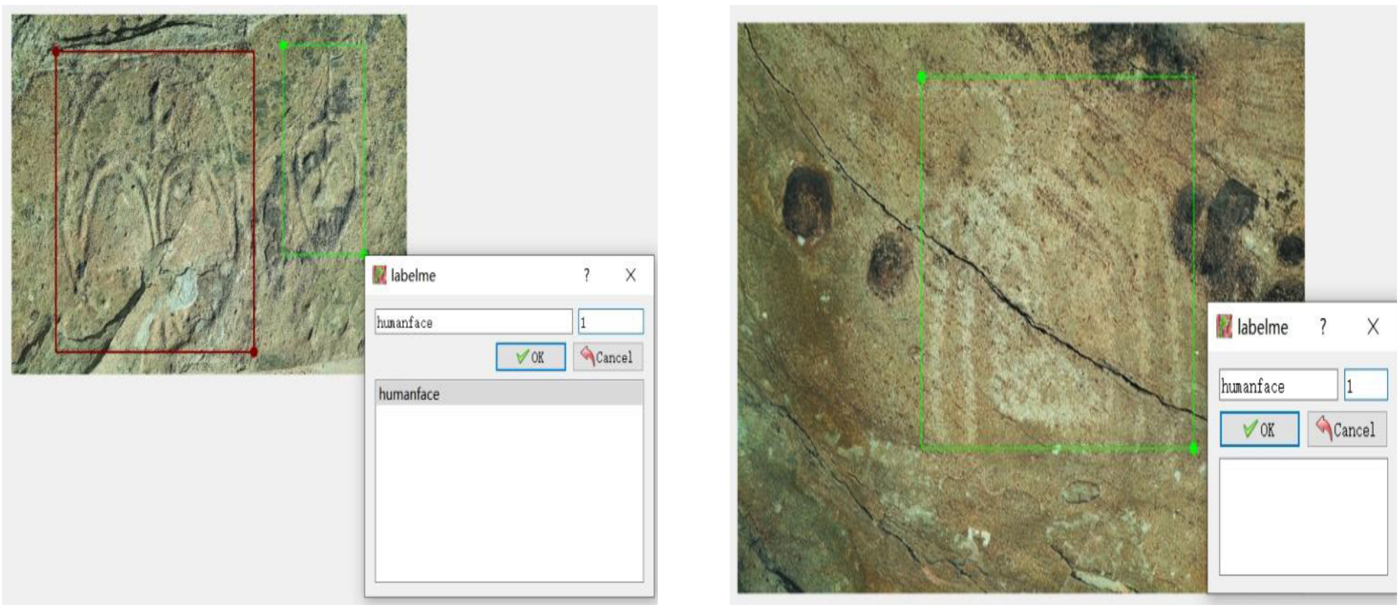


Figure 6: The process of feature labeling creation

(Photographed by Liangliang Xia)

implies that the model can automatically identify and label most Human Face rock art, thereby reducing the workload of manual identification. Especially when dealing with a large number of rock art data, the deep learning model can maintain high consistency, unaffected by fatigue, subjective judgment, or emotional factors, assisting researchers in rock art identification and improving work efficiency.

However, there are still areas in the model that require urgent improvement. For example, in the test results, there are cases where the bounding boxes do not fit well, especially in situations containing multiple human face images, as shown in Figure (a), where only one face is detected. There are also instances where a small number of Human Face rock art is not accurately identified, as shown in Figure (c) and Figure (d). The reasons may include the insufficient coverage of all types of Human Face rock art in the training set and inaccuracies in feature label creation, leading to a lack of high generalization ability of the model.To address the above results, it is necessary to expand and refine the dataset in the later stages, collecting more high-resolution rock art image data and incorporating additional image data augmentation algorithms to enhance the quality and diversity of the dataset. Additionally, exploring the use of transfer learning methods, pre-training on human face image data from other regions, fine-tuning parameters, and then training on the dataset of Human Face rock art in Helan Mountain could be attempted.

5. CHALLENGES

Human Face rock art, as images drawn by ancient ancestors on rocks, has undergone the passage of countless years, presenting numerous challenges and difficulties in the identification process. In China, Human Face rock art is relatively scattered in distribution. Taking the

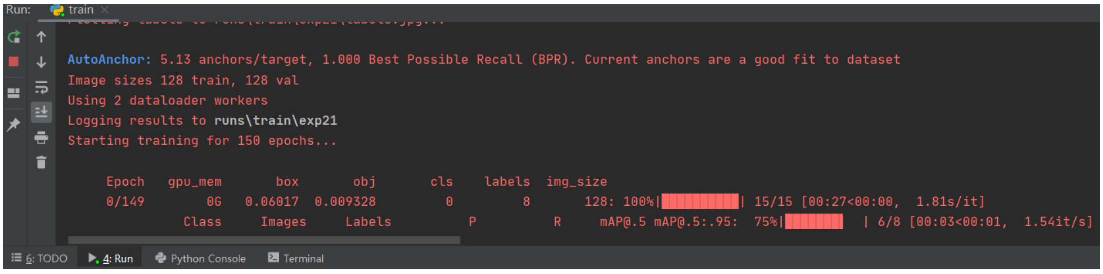
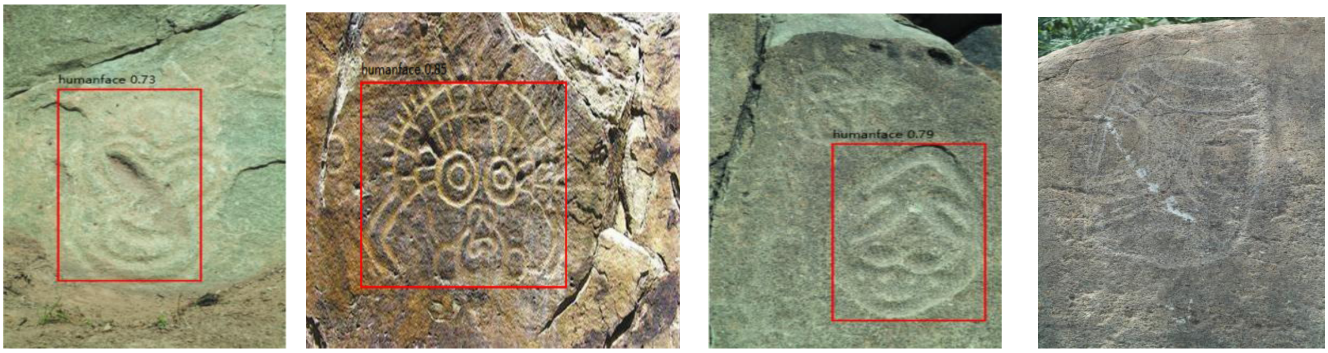


Figure 7: Model training process



(a) (b) (c) (d)

Figure 8: Partial test results display

(Photographed by Liangliang Xia)

example of the Helan Mountain rock art in Ningxia, it is mainly found in more than 20 rock art sites such as Daxifeng Gou, Xiaoxifeng Gou, Baihu Gou, Chaqikou, Helankou, and Baisikou. Helankou is considered representative of Human Face rock art, with over 200 Human Face rock art concentrated on the cliffs on both sides of the valley (An, Y., 2012.). Additionally, Human Face rock art is also found on cliffs and precipices in other regions. Due to the complex distribution of these Human Face rock art, there is a considerable risk in conducting on-site verification. Over thousands of years, Human Face rock art has suffered from natural weathering and erosion, some have peeled off and detached, and others have become difficult to identify and restore, posing significant challenges to research. In recent years, with the increasing efforts in the conservation of Human Face rock art and the application of various modern scientific technologies in rock art preservation, the lifespan of Human Face rock art has been extended to some extent. However, it is still impossible to avoid rock art damage. Therefore, it is essential to further strengthen supervision, formulate more comprehensive rock art conservation policies, and establish a comprehensive protection system for Human Face rock art. In addition, there are two challenges faced in the identification of Human Face rock art.

5.1 The Database of Human Face rock arts Has Not Yet Been Built

In the identification and comparison of Human Face rock arts, the most crucial step is the construction of a digital recognition model. During this process, it is necessary to train the model through deep learning, which requires a sufficient amount of carefully selected and processed data to form a training set. This is not only a prerequisite for training a highly accurate recognition model, but also a reflection of fully utilizing rock art resources. However, due to various factors, apart from a few rocks art management and research institutions such as the Helan Mountain Rock Art Management Office, there is currently no authoritative organization that can integrate the rock art cultural resources nationwide even global and establish a digital integrated system of rock art covering all rock art sites, with functions of storage, publicity, education, development, and utilization.

5.2 Difficulty in Precise Identification

In the current research on human face rock art identification, our method primarily focuses on the analysis and recognition of the images themselves. However, this approach to judging human face rock art is preliminary and cannot guarantee that the images we identify are indeed created by humans. These images may also have formed gradually over a long period under the influence of natural factors. The algorithms used in this study currently lack the capability to determine whether an image is artificially made, and human judgment may be required after the identification process. In future research, adjustments to machine learning strategies can be explored to enhance the ability to judge certain features of the images. For example, artifacts created by humans may exhibit certain regular geometric shapes or patterns, while natural factors may show higher randomness. Strengthening the model's ability to identify these features can improve its a priori judgment ability, allowing for further recognition work after confirming the nature of the image as rock art. Therefore, under current conditions, we still rely on manual research or other auxiliary technologies to confirm whether an image is artificially created rock art. For instance, in-depth analysis of the image's color, shape, and texture, searching for regular and geometric features, can significantly increase the likelihood that the image is rock art. Additionally, geological studies can be employed to confirm whether the image's formation is related to geological processes, thus assessing its correlation with natural factors.

Moreover, certain inherent features of human face rock art pose challenges to image recognition. It is well-known that the structure of human faces is generally consistent, with differences mainly in details. However, original human face rock art exhibits a wide variety of types and styles, with many not having typical facial features and appearing highly abstract. Some human face rock art even appears in groups, as shown in Figure 9. There are many such abstract and unique human face rock art, making the precise identification of these types a major challenge in the current research.

6. CONCLUSION AND FUTURE WORKS

Similarity calculation can help us understand the connections and differences between different human face rock art, providing a new means for exploring cultural connotations. By comparing the similarity of rock art images, we can judge the commonalities and differences between rock art from different periods, locations, and styles. This provides new evidence for the classification and cultural research of

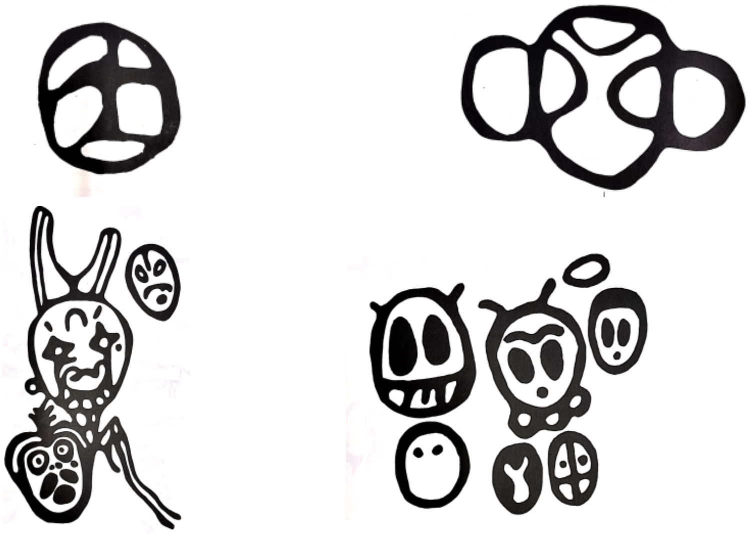


Figure 9: Abstract Human Face Rock Art and Human Face Rock Art Group

(Sourced from 'Rock Arts of the Helan Mountains')

human face rock art. Traditional manual identification methods, when faced with a large number of rock art, not only rely on professional researchers but also consume a considerable amount of time and effort, with identification criteria difficult to consistently maintain. The application of object detection algorithms can help us quickly identify human face rock art, assisting researchers in rock art studies. These methods also allow us to understand these ancient artworks from new perspectives, demonstrating practical value.

Currently, many rock art research institutions at home and abroad use deep learning methods for rock art research, essentially achieving the function of rock art object detection and identification. In the future, deep learning methods may have more extensive applications in rock art research, such as automatic classification of rock art, construction of rock art chronology, extraction of rock art line drawings, rock art restoration, and the non-destructive transformation of hand-copied tracings into electronic tracings. Therefore, we should promote the integration of technology and rock art to drive new breakthroughs and advancements in rock art research.

Acknowledgements

The Interim Achievement of the Major Project on Philosophical and Social Sciences Research by the Ministry of Education in 2022:'Research on Chinese Rock Art' (Project Number: 22JZD032).

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