A Comparative Study and Analysis of Computer Vision Technology and 3D Scanning Technology in the Identification of Yao Ethnic Silver Ornaments

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Abstract: As intangible cultural heritage, the silver ornaments of the Yao ethnic group carry unique cultural and artistic values. The intricate patterns and details of Yao silver ornaments pose significant challenges to digital protection technologies. In this paper, we compare the performance differences between traditional computer vision techniques (Canny edge detection, scale-invariant feature transform (SIFT) feature extraction) and 3D scanning technologies (time-of-flight (ToF), 3D point cloud data processing (3DPCDP)) in recognizing the characteristics of Yao silver ornaments. The study results show that computer vision techniques have high computational efficiency in simple edge detection and feature point matching, but their capabilities are limited when it comes to capturing complex textures and 3D structures. On the other hand, 3D scanning technology significantly improves the accuracy of identifying fine structural features by modeling depth data, but it has the drawbacks of high computational costs and lack of real-time performance. The research indicates that the combined application of these two technologies can achieve a balance between efficiency and precision. When combined with deep learning optimization algorithms, it can provide a more comprehensive solution for the digital protection and inheritance of Yao silver ornaments.

Keywords: Computer Vision Technology; 3D Scanning Technology; Feature Recognition

1. Introduction

The silver ornament-making skills of the Yao people are traditional handicrafts that embody the imagination of the Yao people. The patterns and designs are diverse, carrying auspicious meanings such as good fortune and warding off misfortune. For the Yao people, particular attention is paid to the patterns and designs on their silver ornaments [4]. These patterns and designs on Yao silver ornaments reflect the identity of the Yao people in tracing their ethnic roots. However, under the impact of modernization, Yao silver ornaments face a crisis of inheritance. Traditional physical protection and manual recording methods cannot meet the high-precision, large-scale digital archiving requirements.

In recent years, computer vision and 3D scanning technology have emerged as new methods for the digital preservation of cultural heritage. Many scholars have conducted research on applying computer vision techniques to the protection of cultural heritage. For example, Li Yufeng et al. proposed an image stitching algorithm based on region block and scale-invariant feature transformation (SIFT) in (2016), achieving certain results in the field of image stitching. This algorithm extracts and matches feature points using SIFT to achieve image stitching. However, when processing complex textures and images with significant lighting changes, the accuracy of feature point extraction and the stitching effect can be affected.

In the research on 3D scanning technology, Wang Yin (2017) modeled and analyzed the errors of Time-of-Flight (ToF) method used in three-dimensional imaging [5], providing a theoretical foundation for the application of ToF technology in 3D imaging. However, this technology has issues such as high computational costs and poor real-time performance during data acquisition and processing.

In computer vision technology, Canny edge detection and SIFT feature extraction can more quickly identify the planar textures of Yao ethnic silver ornaments. However, when these methods are used to process three-dimensional carvings and complex textured structures of Yao ethnic silver ornaments, the results are not very good. On the other hand, if time-of-flight (ToF) and 3D point cloud data processing (3DPCDP) in 3D scanning technology are used, they can accurately reconstruct the three-dimensional shape of the silver ornaments, which yields excellent results; however, this requires high computational costs and specialized equipment support. This paper will compare these two techniques from five aspects: feature extraction methods, recognition accuracy, robustness, computational speed, and stability, and analyze their suitable application scenarios to provide theoretical support for the digital inheritance of Yao ethnic silver ornaments.

2. Analysis of Characteristics of Yizu Silver Ornaments

The characteristic analysis of Yizu silver ornaments is an important feature for the evaluation of image processing algorithm types, and its unique focus is on pattern features and pattern features.

2.1 Pattern Theme Characteristics

In the silver ornaments of the Yao people, the patterns widely incorporate elements of totem worship. The most unique are the human figures, featuring images of the Yao ancestors Pan Wang and heroes like Fa Zhen, as well as the "malevolent deities" symbolizing good fortune and safety. These elements frequently appear in Yao silver ornaments. For example, in the silver ornament-Silver Demon (Yuebei Yao), carved in the central part of the Silver Demon (Yuebei Yao), there are depictions of the ancestor Pan Hu or the Yao hero "Fa Zhen." These heroic figures are typically presented in semi-relief, with a powerful and lifelike appearance.

2.2 Characteristics of Natural Patterns

In the common natural themes of YAO silver ornaments, most of the inspiration comes from the wonderful scenes of nature, such as birds and beasts, wild flowers and grass, and flowing clouds. The Yao people inject the scenes of life into the silver ornaments, highlighting their love for life.

2.3 Characteristics of Geometric Patterns

Compared to the silver ornaments of the Yao people, geometric patterns are not only complex and varied but also diverse in type. For example, human figures, sun patterns, intersecting designs, and pine tree motifs. These geometric patterns are simple in form yet orderly arranged, exquisitely beautiful. The Yao people have also endowed these geometric designs with different artistic connotations and unique meanings, enriching their expressive forms. This makes the geometric patterns not only aesthetically pleasing but also carry unique cultural significance for the Yao people.

3. Application of Computer Vision in the Identification of Characteristics of Yao Silver Ornaments

3.1 Edge Detection Algorithm: Canny

Gaussian filtering: The surface texture of the Yao ethnic silver ornaments photographed through a camera may contain a large amount of high-frequency noise, affecting the accuracy of edge detection. To reduce the impact of high-frequency noise on edge detection, it is necessary to first apply Gaussian filtering to the input image of the silver ornaments. This process linearly smooths the image and reduces the irregular noise in the silver ornament texture. The convolution formula for the Gaussian filter is:

$$I_{soomth}(x,y)=I(x,y)*G(x,y,\sigma) \quad (1)$$

among

$$G(x,y,\sigma)=\frac{1}{2\pi\sigma^2}\exp(-\frac{x^2+y^2}{2\sigma^2}) \quad (2)$$

σ is used to control the standard deviation of the Gaussian filter, which determines the smoothness of the silver surface.

Second gradient calculation: The Sobel operator is used to calculate the image gradient of the surface of Yao ethnic silver ornaments, to determine the direction and intensity of the edges. The Sobel operator is particularly suitable for extracting geometric edges on the surface of silver ornaments, such as the edges of the Yao ethnic ten-row dragon pattern chiseled silver necklace and the edges of silver drums and other silver ornaments. The two directional components of the gradient are:

$$G_x=\frac{\partial I_{smooth}(x,y)}{\partial x}\ G_x=\frac{\partial I_{smooth}(x,y)}{\partial y} \quad (3)$$

The gradient amplitude G and direction θ can be calculated by the following formula:

$$G=\sqrt{G_x^2+G_y^2}\ \theta=\arctan(\frac{G_y}{G_x}) \quad (4)$$

For the complex structure of yao silver ornaments, the direction of gradient can help identify the change of edge direction.

Thirdly, the double threshold method: through analysis, two thresholds T_{low} and G_{high} are used to process the gradient image after non-maximum suppression and perform binarization. This step can distinguish different edge information of different intensities, ensuring that the detected edges truly reflect the boundary of silver ornaments. The specific rules are as follows:

When $G(x,y)>T_{high}$, it is marked as a strong edge (such as the boundary between silver demon and silver ornament);

When $T_{low}\leq G(x,y)\leq T_{high}$, it is marked as weak edge (fine cracks or scratches on the surface of silver ornaments);

When $G(x,y)<T_{low}$, the pixel is inhibited.

Fourth, lagging edge tracking: in the detection of Yao silver ornaments, if the weak edge (small cracks or scratches) is connected with the strong edge (silver demon border), the weak edge is retained as the real edge; otherwise, it is suppressed.

3.2 Feature Point Extraction Algorithm SIFT

Construction of scale space and recognition of scale features:

In the process of feature recognition for Yao ethnic silver ornaments, the construction of different scale spaces is crucial for accurately identifying the image details of Yao ethnic silver ornaments. The SIFT algorithm applies Gaussian filters to smooth the images at different scales, resulting in a scale space. The scale space is represented as:

$$L(x,y,\sigma)=G(x,y,\sigma)* I(x,y) \quad (5)$$

Among them, $I(x,y)$ represents the input image of silver ornaments, and $G(x,y,\sigma)$ is the Gaussian kernel function:

$$G(x,y,\sigma)=\frac{1}{2\pi\sigma^2}\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \quad (6)$$

For the feature extraction of silver jewelry structure, different σ values are helpful to identify the structural features at different scales. For different types of Yao silver ornaments such as the Silver Demon Crown, Silver Tree, and Golden Bell, these images exhibit unique characteristics at various scales. For example, the image of the Yao hero "Fazhen" on the Silver Demon Crown and its surrounding totems can clearly display detailed textures at smaller scales, while it is easier to capture the overall shape at larger scales. By recognizing different multi-scale spaces, feature points [6] of varying sizes can be detected, providing foundational material for subsequent feature extraction and matching.

Extreme point detection, find the key point:

The Gaussian difference operation in SIFT algorithm is used to detect feature points. In the feature recognition of Yao silver ornaments, the key points of silver ornaments at different scales can be obtained.

$$D(x,y,\sigma)=L(x,y,k\sigma)-L(x,y,\sigma) \quad (7)$$

Through the above formula, at the edge of the silver drum or the connection point of the silver necklace, the algorithm compares a pixel in the silver ornament with its surrounding 26 pixels to find the corresponding local extremum. These identified extrema will represent feature points at specific locations on Yao ethnic silver ornaments, which is crucial for accurately constructing the geometric shape and structure of these ornaments.

Positioning feature points to enhance accuracy:

The Taylor series is used to accurately locate each local extremum point. In the silver ornaments of the Yao ethnic group, such as the carving parts and complex connection parts of the silver tree, feature points are positioned:

$$\hat{x}=-\frac{\partial^2 D^{-1}}{\partial x^2}\frac{\partial D}{\partial x} \quad (8)$$

It can remove points with low contrast or weak edge strength and improve the accuracy of features. It is very important for fine detection of complex structures of Yao silver ornaments.

Directional allocation to ensure rotation invariance:

During the process of recording Yao ethnic silver ornaments, the camera is usually positioned around the silver ornaments. To ensure the stability of feature points on the silver ornaments during shooting, the SIFT algorithm is used to calculate the gradient direction of the area around the feature points and allocate the main movement direction. The gradient magnitude $m(x,y)$ is expressed as:

$$m(x,y)=\sqrt{(L_x(x,y))^2+(L_y(x,y))^2} \quad (9)$$

Direction $\theta(z,y)$ is indicated as follows:

$$\theta(x,y)=\tan^{-1}\left(\frac{L_y(x,y)}{L_x(x,y)}\right) \quad (10)$$

The generation of feature point descriptor accurately describes the key points of silver ornaments:

In the study of Yao ethnic silver ornaments, images of the silver ornaments are used to generate a 128-dimensional descriptor by calculating the gradient direction within the neighborhood of image feature points. The descriptor is based on 4*4 subregions, where the gradient histogram for 8 directions is calculated in each subregion, ultimately resulting in a 128-dimensional feature vector.

$$f=[h_1,h_2,\ldots,h_{128}] \tag{11}$$

Feature point matching, detection of structural changes or damage:

The feature points are matched by calculating the Euclidean distance between the descriptor of different images of Yao silver ornaments. In the monitoring and protection of Yao silver ornaments, the structural changes or damages of silver ornaments can be detected by means of feature point matching.

$$d(f,f')=\sqrt{\sum_{i=1}^{128}(f_i-f_i')^2} \tag{12}$$

Based on the above formula, SIFT algorithm can be used to identify wear, scratches and deformation of silver ornaments from different angles, providing scientific basis for the repair and protection of silver ornaments.

4. Application of 3D Scanning Technology in the Identification of Silver Ornaments of Yao Ethnic Group

4.1 Time of Flight Method (ToF)

In 3D scanning technology, LiDAR acquires distance information by emitting laser pulses and measuring the time it takes for the laser to be reflected back to the sensor. The principle is based on the Time of Flight (TOF) [5]. The lidar beam is fired and reflected to the sensor when it hits the surface of the silver ornament. The round-trip time t_2-t_1 of the light can be calculated through the emission time t_1 and the reception time t_2 of the laser pulse. Given the speed of light c, the distance from the object to the lidar is:

$$r=\frac{c\times(t_2-t_1)}{2} \tag{13}$$

Through the above formula, the lidar can continuously emit and receive laser pulses to obtain the depth data of silver ornaments and establish the corresponding 3D model of Yao silver ornaments.

4.2 3D Point Cloud Data Processing (3DPCDP)

When 3D scanning technology is applied to the characteristic identification of Yao silver ornaments, the data collected by lidar are stored in the form of point cloud through 3D point cloud data processing, and the three-dimensional coordinates (x, y, z) and reflection intensity information of each point of silver ornaments are recorded.

Noise filtering:

After statistical filtering, the statistical features within each point neighborhood in the point cloud data of Yao ethnic silver ornaments are analyzed, such as distance and density. Outliers are identified and removed to reduce the impact of image noise on the overall model. The collected point cloud data undergoes denoising and image smoothing processing to enhance the data quality of the 3D silver ornament model, minimize noise interference, and facilitate subsequent analysis and use.

Point cloud registration:

In the process of feature recognition of Yao silver ornaments by 3D scanning technology, point cloud registration is extremely important because the point cloud data obtained from different perspectives have positional differences when the actual data is collected. If not processed, it will seriously affect the analysis of Yao silver ornaments features and model construction [2].

The iterative closest point (ICP) algorithm is continuously optimized to solve the appropriate rotation matrix R and translation vector T. In this process, the Euclidean distance between the source point cloud Q_1 and the target point cloud P is minimized, that is:

$$R,T=\operatorname{argmin}\sum_i \|P_i-(RQ_i+T)\|^2 \tag{14}$$

Through the above formula, the optimal rotation matrix R and translation vector T are obtained. Then, the source point cloud Q_1 is transformed by corresponding rotation and translation to align with the target point cloud P, so as to achieve accurate registration of the data point cloud and obtain a fine 3D model of silver ornaments.

Feature extraction and segmentation:

After the above steps, with the help of normal vector, curvature and other characteristics, through the following formula:

$$H=\frac{1}{2}(k_1+k_2) \tag{15}$$

The point cloud data after noise reduction and registration processing are reasonably divided. For the complex concave structure and fine texture changes of the pattern of Yao silver ornaments, three-dimensional information can be used to achieve more accurate capture, which is conducive to in-depth analysis of the characteristics of Yao silver ornaments.

5. Comparative Analysis of Technologies

5.1 Feature Extraction Method

In computer vision, Canny edge detection extracts the edge information of silver ornaments from two-dimensional images through a series of steps including Gaussian filtering, gradient calculation, dual threshold method, and lagged edge tracking; SIFT feature point extraction, on the other hand, involves detecting, locating, and assigning directions to extremum points, generating descriptors, and matching based on the scale space of the silver ornament model, primarily focusing on extracting feature points of the silver ornament. These methods mainly rely on manually designed features and fixed mathematical models to mine the characteristics of silver ornaments from grayscale and gradient information in the image.

In 3D scanning technology, such as the time-of-flight method, depth data of Yao ethnic silver ornaments is obtained by emitting and receiving laser pulses with a LiDAR, thus creating a 3D model of the silver ornament; during the 3D point cloud data processing stage, operations like noise filtering, point cloud registration, and feature extraction and segmentation based on normal vectors and curvature are used to capture the shape, structure, and texture characteristics of the silver ornament from a three-dimensional perspective. Compared to computer vision, 3D scanning technology can obtain richer spatial information.

5.2 Accuracy

Computer vision is highly efficient at processing simple image edges and feature points, but it has obvious limitations when dealing with the complex textures of Yao ethnic silver ornaments. Canny edge detection may misjudge or lose edges due to noise generated by the surface texture of the silver ornament, while SIFT feature point extraction can be affected in accuracy under complex backgrounds or changes in lighting. In contrast, 3D scanning technology can better capture and analyze the complex features of silver ornament images [1]. By constructing a 3D model of the silver ornament using the obtained depth data, the shape and structure of Yao ethnic silver ornaments can be accurately reconstructed. This approach offers advantages in handling complex concave-convex structures and subtle texture variations, providing more accurate reflection of the true characteristics of the silver ornaments and offering more reliable data support for subsequent research and conservation efforts.

5.3 Calculation Efficiency

In computer vision, the Canny edge detection and SIFT feature point extraction processes are relatively simple. In resource-limited scenarios, when the amount of silver jewelry image data is small, the computational efficiency is higher. However, when dealing with large volumes of complex silver jewelry image data, especially high-resolution images, the computational load significantly increases, leading to a decrease in efficiency.

In 3D scanning technology, the process of acquiring data and processing 3D point cloud data is relatively more complex compared to computer vision, requiring more resource consumption. Operations such as lidar data collection [3] and point cloud registration involve a large amount of computation, especially when processing high-precision scanning data for complex silver ornaments, where computational efficiency is lower.

5.4 Robustness

Traditional computer vision methods have obvious limitations: under changing lighting conditions, the grayscale distribution on the surface of silver jewelry can fluctuate; in strong light, mirror reflection may cause the Canny algorithm to misjudge edges; in low-light environments, insufficient contrast can result in detail loss. Additionally, image noise can interfere with SIFT feature point extraction, and texture deformation caused by changes in perspective can affect feature matching performance.

In contrast, 3D scanning technology boasts superior environmental adaptability: depth measurements based on Time of Flight (ToF) are unaffected by ambient light intensity; point cloud filtering can effectively eliminate acquisition noise and smooth the image; meanwhile, multi-view data registration algorithms can accurately integrate scan data from different poses, fully reconstructing the three-dimensional structure of silver jewelry.

Table 1. Comparative Analysis

Evaluation dimension	computer vision (Canny, SIFT)	3D scanning (ToF, 3DPCDP)
Feature extraction method	Canny Extract edge information from two-dimensional images; SIFT extracts feature points, mainly using image grayscale and gradient information	ToF Obtain depth data to build 3D models; 3DPCDP Capture shape, structure and texture features from three-dimensional space
Feature recognition accuracy	It is higher under simple edges and clear features; it is slightly inferior under complex textures	It has a stronger ability to capture complex textures and fine structures
computational efficiency	The algorithm is mature and fast processing, suitable for low cost scenarios	The data volume is large and the processing time is long, so high performance equipment is required.
robustness	It is sensitive to light and noise; the matching rate decreases when the angle changes.	Relying on depth information, it has good robustness and can adapt to complex scenes
applicable scene	Real-time requirements are high, computing resources are limited, and complex features are not required	It is required to have high accuracy in restoring the complex structure and fine texture of silver ornaments, and is insensitive to the cost of calculation and time
Application advantages	The calculation efficiency is high, the algorithm is mature, and the equipment requirements are relatively simple.	It can obtain rich three-dimensional information and accurately restore the real shape of silver ornaments
Application limitations	The ability to capture complex texture, depth information and three-dimensional structure is limited, and it is easy to be disturbed by environmental factors	The cost of calculation is high, the performance of equipment is high and the real-time performance is poor

Through the above comparison, in the practical life of identifying characteristics of Yao ethnic silver ornaments, different usage scenarios have significantly different requirements for recognition technology. Computer vision and 3D scanning techniques each have their own advantages and limitations in silver ornament feature recognition; a single technical approach cannot meet all practical application needs. It is recommended to adopt a phased integration method: first, use computer vision technology to quickly obtain surface texture features of the silver ornaments, then utilize 3D scanning technology to acquire precise spatial structure data. This segmented combination approach can effectively avoid issues such as light sensitivity. This will provide more reliable theoretical support for the research, protection, and inheritance of Yao ethnic silver ornaments.

6. Conclusion

Through the analysis and comparison of the entire text, computer vision technology and 3D scanning technology each have their own advantages and disadvantages in the practical application of Yao ethnic silver ornaments. Computer vision technology relies on edge detection and feature point extraction, showing significant advantages in simple edge and geometric structure recognition, with fast computation speeds suitable for scenarios with high real-time requirements or limited computational resources. However, it has limited capabilities in capturing complex textures, depth information, and three-dimensional structures, and its recognition accuracy tends to decline under lighting, angle, and background interference. 3D scanning technology can obtain depth information, fully restoring the three-dimensional form and intricate details of silver ornaments, demonstrating clear advantages in recognizing fine carvings and other subtle features. However, data acquisition and processing are complex, computational costs are high, and equipment performance requirements are stringent, making it less effective than computer vision technology in scenarios with high real-time demands.

From the perspective of cultural heritage protection and the digital development of Yao ethnic silver ornaments, a single technology cannot meet practical needs. In future conservation processes, it is necessary to analyze usage scenarios for application. At the same time, combining individual strengths can achieve efficient and precise identification. Deep learning can also be utilized, with neural network feature extraction methods improving the accuracy of complex texture recognition in computer vision, optimizing 3D point cloud data processing algorithms to reduce costs and enhance efficiency.

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