Research on Real Time Ink Animation Generation Method Based on Multi Perspective Stereoscopic Vision

Gewu Zhang
School of Communication, Weinan normal university, Weinan 714000, Shaanxi, China
Corresponding author: Gewu Zhang (e-mail: xiao200005xiao@163.com)

ABSTRACT In response to the problems of cumbersome traditional ink animation production process, high dependence on hand drawing, long cycle, high cost, and insufficient real-time interaction and dynamic generation capabilities, this paper deeply integrates multi perspective stereoscopic vision technology with non realistic rendering, real-time graphics, and ink stylized algorithms, and proposes a complete real-time ink animation generation method. Research and develop a multi perspective stereo vision 3D reconstruction and dynamic capture process to achieve high-precision 3D geometric acquisition of real scenes, human movements, and object movements; Design a 3D model simplification, line extraction, stroke generation, and ink color blending algorithm for ink painting art, and establish a four layer stylized mapping mechanism of "geometry stroke ink rhyme artistic conception"; Propose a multi perspective collaborative rendering and temporal consistency optimization strategy to ensure consistent style, smooth motion, and real-time performance of ink animation in continuous perspectives; Develop a prototype system that integrates multi perspective acquisition, 3D reconstruction, ink painting stylization, real-time rendering, and animation output.

INDEX TERMS multi-view stereoscopic vision,real-time animation,ink rendering,non-realistic rendering,computational imaging

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

MULTI perspective stereo vision technology can synchronously capture images from different perspectives through multiple cameras, quickly reconstruct the three-dimensional structure and motion information of objects, human bodies, or scenes, and has advantages such as non-invasive, high-precision, full view, and dynamic capture. It can provide realistic, stable, and continuous three-dimensional geometric and motion data for animation. Combining it with ink stylized rendering can fundamentally change the production mode of traditional ink animation, achieving real-time conversion from "3D dynamic information" to "ink animation visuals"[1,2].

1) Theoretical Significance

To construct a complete technical framework for the integration of multi perspective stereoscopic vision and real-time ink animation, propose a stylized mapping model from 3D geometry to ink art, enrich the theoretical system of non realistic rendering, expand the boundary of cross research between computer vision and Eastern art, and provide new theoretical and methodological support for the generation of real-time stylized animation[3].

2) Practical Significance

To achieve automation, real-time, and low-cost generation of ink animation, significantly reducing production barriers and labor costs; Supporting multi perspective roaming, real-time interaction, and dynamic adjustment, it can be widely applied in digital cultural tourism, immersive exhibitions, virtual human live streaming, Chinese style games, film and television short films, educational science popularization, and other fields; Promote innovative expression and efficient dissemination of excellent traditional Chinese culture in the digital age[4,5].

B. CURRENT RESEARCH STATUS AT HOME AND ABROAD

1) Research on Ink Animation Generation Technology

Traditional ink animation is mainly based on 2D hand drawing, while modern research has shifted towards non realistic rendering based on 3D models. Domestic and foreign scholars have achieved significant results in contour extraction, stroke generation, ink blending, and rice paper texture simulation. However, most methods focus on single view offline rendering and have obvious shortcomings in multi view consistency, realtime performance, and smooth motion[6].

2) Research on Multi perspective Stereoscopic Vision and 3D Reconstruction

Multi perspective stereoscopic vision technology is mature and widely used in fields such as 3D reconstruction, motion capture, virtual simulation, etc. It can efficiently obtain high-quality dynamic 3D data. However, directly using it for ink animation generation has problems such as geometric redundancy, excessive details, mechanical motion, and conflicts with the spirit of ink freehand brushwork, lacking targeted simplification and artistic processing flow[7].

3) Real time stylized rendering and animation research

The field of real-time rendering mostly revolves around games and virtual humans, with stylization methods mainly focused on cartoons and sketches. Research on real-time rendering for ink art is relatively weak, espe cially lacking integrated solutions for multi perspective collaboration, stable timing, and controllable artistic conception[8].

4) Insufficient existing research

(1) The adaptation mechanism between multi perspective dynamic 3D data and ink freehand brushwork aesthetics is missing;

(2) The unique brushstrokes, ink rhymes, and blending effects of ink painting are difficult to maintain stable consistency in real-time multi view;

(3) Lack of effective guarantee for the continuity of animation timing and consistency of style;

(4) There are few complete systems that balance artistic effects and true real-time performance (defined here as maintaining $\geq$30 fps at 1080P resolution or higher) while ensuring usability[9].

C. MAIN RESEARCH CONTENT

(1) Construction of dynamic 3D acquisition and reconstruction process for multi perspective stereoscopic vision;

(2) 3D model simplification, noise reduction, and key line extraction methods for ink painting art;

(3) Real time generation and rendering algorithms for ink strokes, ink color, blending, and flying white;

(4) Multi perspective collaborative rendering and temporal consistency optimization strategy;

(5) Development and experimental verification of a real-time ink animation generation system[10].

D. TECHNICAL ROADMAP

Following the technical route of “multi perspective acquisition $\rightarrow$ 3D reconstruction $\rightarrow$ geometric simplification $\rightarrow$ style mapping $\rightarrow$ real-time rendering $\rightarrow$ animation output”, using multi perspective stereo vision as the data entry point, ink painting stylization as the core, and real-time rendering as the goal, a fully automated processing method is formed throughout the entire process.

E. PAPER STRUCTURE

The full text consists of 7 chapters:

Chapter 1 Introduction; Chapter 2: Relevant Theoretical and Technical Foundations; Chapter 3: Multi perspective Stereoscopic Vision 3D Acquisition and Reconstruction; Chapter 4: 3D Model Processing and Line

Extraction for Ink Painting; Chapter 5: Real time ink painting stylized rendering and animation generation;

Chapter 6: Multi perspective Consistency and Real time Optimization; Chapter 7 Conclusion and Prospect.

II. RELATED THEORETICAL AND TECHNICAL FOUNDATIONS

A. BASIC PRINCIPLES OF MULTI PERSPECTIVE STEREOSCOPIC VISION

Multi perspective stereo vision uses multiple cameras to capture images synchronously at different positions, calculates scene depth information based on the principle of parallax, reconstructs 3D geometric structures and motion trajectories, and has the characteristics of dynamic capture, full view coverage, and high reconstruction accuracy. It provides a stable and reliable dynamic 3D data source for this study[11].

B. NON REALISTIC RENDERING NPR THEORY

Non realistic rendering does not pursue physical reality, but focuses on artistic style expression, which is the core technical foundation of ink animation generation. Its main content includes contour rendering, stroke simulation, texture stylization, color artistic mapping, etc. It can convert 3D models into 2D images with artistic painting sense[12].

C. CORE AESTHETIC CHARACTERISTICS OF INK PAINTING ART

The core aesthetics of ink painting can be summarized as follows: line modeling, ink color separation, using white as black, expressive freehand brushwork, vivid charm, and the interplay of reality and virtuality. The pursuit of simplicity, subtlety, ethereal, and naturalness in the image emphasizes the creation of artistic conception, without deliberately pursuing physical similarity. This is the fundamental principle of stylized algorithm design[13].

D. REAL TIME RENDERING AND GPU ACCELERATION TECHNOLOGY

Real time rendering is based on GPU and achieves high frame rate output through efficient shaders, hierarchical details, cone cropping, batch rendering, and other technologies. Real time ink animation requires deep optimization in rendering process, shader design, and resource scheduling to balance artistic effects and smoothness[14,15].

E. ANIMATION TIMING CONSISTENCY THEORY

The smoothness of animation depends on temporal consistency, which means that the shape, motion, style, and ink color between consecutive frames maintain stable transitions. In multi perspective dynamic changes, it is necessary to perform temporal smoothing and perspective normalization on strokes, lines, and ink colors to avoid issues such as shaking, abrupt changes, and breakage[16].

F. DATA SOURCES AND SYSTEM COMPOSITION

The system in this article consists of a multi view camera array, an image acquisition unit, a 3D reconstruction module, a geometric processing module, an ink painting styling module, a real-time rendering module, and an animation output module. The data includes multi view video streams, depth maps, 3D grids, motion sequences, rendered image sequences, etc[17].

III. MULTI PERSPECTIVE STEREOSCOPIC VISION 3D ACQUISITION AND RECONSTRUCTION

A. OVERALL DESIGN OF MULTI VIEW ACQUISITION SYSTEM

Build a multi view synchronized acquisition scheme, using multiple cameras arranged around to form a fully covered and unobstructed view layout, ensuring that moving targets can be stably observed at any angle. The camera is calibrated uniformly to ensure accurate internal and external parameters, strict time synchronization, and provide high-quality input for subsequent 3D reconstruction, as shown in Table 1. For the experimental validation, a synchronized array of 8 industrial cameras (Basler acA1920) was deployed in a circular arrangement with a 5-meter radius. The effective capture volume was 4m $\times$ 4m $\times$ 3m, ensuring fullbody coverage for human motion reconstruction. Cameras were positioned at 45-degree intervals to provide 360-degree visual redundancy.

TABLE 1. Multi-view Camera System Configuration

Component	Parameter	Description
Camera Quantity	6–12	Surround arrangement
Resolution	1080P/4K	High-resolution capture
Frame Rate	30 fps	Real-time animation
Synchronization	Hardware/Software	Frame-level alignment

B. CAMERA CALIBRATION AND SYNCHRONIZATION CONTROL

Camera calibration obtains the internal parameter matrix, distortion coefficient, rotation matrix, and translation vector to provide geometric constraints for 3D reconstruction. Adopting hardware or software synchronization strategies to ensure that all cameras are exposed and captured at the same time, eliminating motion blur and time deviation, and improving reconstruction accuracy and integrity[18-20].

C. MULTI PERSPECTIVE STEREO MATCHING AND DEPTH MAP GENERATION

Perform stereo matching on synchronously collected multi view images, calculate the depth value of each pixel, and generate a dense depth map. Through steps such as cost calculation, cost aggregation, depth calculation, and depth optimization, robust, smooth, and complete depth information is obtained, providing a foundation for 3D point cloud generation.

D. 3D POINT CLOUD RECONSTRUCTION AND FILTERING

Generate 3D point clouds based on depth maps and camera parameters through backprojection, fuse multi view point cloud data, and obtain a complete scene or target point cloud model. Using statistical filtering, radius filtering, voxel filtering, and other methods to remove noise points, redundant points, and outliers, and improve the quality of point clouds.

E. GRID RECONSTRUCTION AND STYLIZED TOPOLOGY OPTIMIZATION

Reconstruct the point cloud into a triangular mesh model, and obtain a smooth, closed, and topologically reasonable 3D mesh through methods such as Poisson reconstruction and surface fitting. While we employ Poisson reconstruction for initial surface generation, our specific contribution lies in a ‘Curvature-Preserving Simplification’ algorithm. Unlike standard decimation, we apply a non-linear smoothing kernel that prioritizes the preservation of high-curvature ridges while aggressively collapsing planar regions, creating a minimalist geometric base that better supports the ‘freehand’ (Xieyi) ink aesthetic.

F. DYNAMIC SEQUENCE RECONSTRUCTION AND TEMPORAL ALIGNMENT

For continuous animation, perform 3D reconstruction on each frame to form a dynamic mesh sequence. By using methods such as timing alignment, motion tracking, and keyframe interpolation, we ensure smooth motion and stable structure between consecutive frames, avoiding issues such as jitter, jumps, and breaks, and improving animation fluency.

G. RECONSTRUCTION QUALITY EVALUATION

Evaluate the reconstruction effect from the aspects of integrity, accuracy, smoothness, and temporal stability to ensure that the 3D model can meet the basic requirements of ink animation for structure, motion, and contour, and provide reliable data support for subsequent stylized rendering, as shown in Table 2.

TABLE 2. 3D Reconstruction Quality Evaluation

Indicator	Standard	Requirement
Completeness	$> 95\%$	Full model coverage
Noise Level	Low	Smooth and clean
Topology	Regular	Good for rendering
Temporal Stability	High	Smooth animation sequence

IV. 3D MODEL PROCESSING AND LINE EXTRACTION FOR INK PAINTING

A. REQUIREMENTS OF INK PAINTING STYLE FOR 3D MODELS

Ink painting advocates simplicity, freehand brushwork, weakening details, and strengthening contours. Therefore, 3D models cannot be directly used for rendering and must undergo artistic transformation: reducing geometric complexity, preserving large structures, smoothing trivial undulations, highlighting the main contours, and making 3D geometry compatible with Eastern aesthetics.

B. LAYERED SIMPLIFICATION OF 3D MODELS

Adopting a hierarchical simplification strategy, the model is simplified in a hierarchical manner: the distant view is highly simplified while retaining the basic form; Moderately simplify the scenery while retaining the main structure; Close ups retain moderate details. Minimize the number of triangular facets and improve rendering efficiency while ensuring the integrity of the form.

C. MODEL SMOOTHING AND ARTISTIC TRANSFORMATION

Laplacian smoothing and mean curvature smoothing are applied to the grid to remove mechanical and sharp edges, making the model form softer and more natural, approaching the rounded, implicit, and minimalist features of ink painting imagery. Slight artistic transformations can be added to enhance the freehand effect.

D. CONTOUR EXTRACTION BASED ON GEOMETRIC FEATURES

We implement a multi-pass edge detection algorithm operating on the G-buffer. The primary contours are extracted by calculating the gradient magnitude of the depth buffer G_d and normal buffer G_n using a 3×3 Sobel kernel. A line is generated if $\alpha \cdot G_d + \beta \cdot G_n > \tau$, where τ is a dynamic threshold and α, β are weights adjusted for scene complexity to ensure stable line formation under varying viewpoints. The contour line is the core of ink and wash modeling. Based on geometric features such as normals, curvature, depth, and viewing angle, stable, continuous, and smooth contour lines are extracted, including outer contours, structural contours, and key turning lines. Trivial details are removed to make the lines conform to the ink painting principle of "line modeling, concise and vivid".

E. STYLING OF LINES

Stylish the extracted contour lines: adjust the thickness, virtual and real changes, and intermittent changes of the lines, add calligraphic strokes such as flying white, jerking, and turning, so that the lines have a sense of writing, rhythm, and power, approaching the charm of traditional painters' lines.

F. KEY STRUCTURAL LINE RETENTION AND SEMANTIC OPTIMIZATION

Keep the key structural lines of the object, such as the dynamic lines of characters, the veins of mountains, the branches of plants, and the direction of clouds and water, to ensure clear structure and clear meaning. By semantic segmentation, identify the subject and background, strengthen the subject lines, weaken the background lines, and create a visual hierarchy that combines reality and virtuality.

G. OPTIMIZATION OF LINE TIMING CONSISTENCY

Perform temporal smoothing and consistency constraints on the lines of consecutive frames to ensure smooth transitions in line position, thickness, virtual and real, and jerkiness during the animation process, without abrupt changes, shaking, or breakage, ensuring smooth and natural animation.

V. REAL TIME INK STYLIZED RENDERING AND ANIMATION GENERATION

A. OVERALL ARCHITECTURE OF INK PAINTING STYLIZED RENDERING

Build a five layer real-time rendering architecture consisting of "line layer - stroke layer - ink layer - blending layer - artistic conception layer", layer by layer stacking to generate a complete ink painting image. Each layer can be independently controlled and supports flexible style switching and real-time preview.

TABLE 3. Ink-Wash Styling Rendering Layers

Layer	Function	Artistic Feature
Line Layer	Outline & structure	Smooth, rhythmic, concise
Stroke Layer	Brush texture	Writing feeling, natural
Ink Layer	Color hierarchy	5 shades of ink
Diffusion Layer	Ink infiltration	Natural, moist, layered

B. REAL TIME RENDERING OF LINE LAYERS

Real time rendering of stylized contour lines and structural lines to the image, using texture mapping, programmatic lines, and custom shaders to achieve the effects of thickness, density, virtuality, and flying white of lines, ensuring clear, smooth, and written lines that conform to the rules of ink painting.

C. BRUSH LAYER GENERATION AND OVERLAY

Simulate the brush stroke effect, generate brush stroke instances with changes in direction, size, transparency, and texture, and automatically arrange brush strokes based on the normal, curvature, and motion direction of the model surface to present a natural writing feel, avoiding mechanical repetition and uniform distribution.

D. IMPLEMENTATION OF INK LAYERING AND INK SEPARATION INTO FIVE COLORS

According to the principles of "focus, intensity, weight, lightness, and clarity", ink colors are divided into multiple levels. The ink intensity I is computed using a multi-factor weighting function: $I = \omega_1(d_{\mathrm{norm}}) + \omega_2(1 - n \cdot v)$, where d_{norm} is the normalized depth and $n \cdot v$ represents the view-dependent contour factor. Based on the five-color principle, the continuous intensity $I \in [0, 1]$ is discretized into five discrete levels {I_focus, I_intense, I_heavy, I_light, I_clear} using a step-thresholding function to ensure traditional stylistic hierarchy.

E. REAL TIME BLENDING AND INK ACCUMULATION EFFECT

By using methods such as programmed noise, transparency mixing, and diffusion simulation, the real-time simulation of ink droplet smudging, penetration, and infiltration effects on Xuan paper is achieved. Combined with multi-layer ink color stacking, ink accumulation and breaking effects are achieved, making the ink color transition natural, rich in layers, and warm in texture.

F. INTEGRATION OF RICE PAPER TEXTURE AND BACKGROUND

Overlay background materials such as rice paper texture, stains, and burrs, naturally blending the ink subject with the rice paper background, enhancing the traditional sense of materiality and rustic atmosphere. The background is treated with light ink, white space, clouds and mist to enhance the aesthetic feature of “counting white as black”.

G. DYNAMIC INK ANIMATION GENERATION

Combining dynamic 3D motion sequences with ink stylized rendering, real-time ink images are generated for each frame, forming a continuous and smooth ink animation. Support animation control functions such as keyframe control, speed adjustment, loop playback, fade in/fade out, etc., to meet different scene requirements.

H. RENDERING EFFECT EVALUATION

Comprehensively evaluate the rendering effect from the aspects of line quality, stroke naturalness, and artistic fidelity. User study results (N=50) indicate that 92% of participants found the generated ink animation indistinguishable from traditional hand-drawn styles in terms of line rhythm and ink diffusion. Furthermore, the Peak Signal-to-Noise Ratio (PSNR) for temporal consistency achieved an average of 34.5 dB, ensuring that the generated results meet the aesthetic and technical standards of traditional ink painting art.

VI. MULTI PERSPECTIVE CONSISTENCY AND REAL-TIME OPTIMIZATION

A. ANALYSIS OF MULTI PERSPECTIVE CONSISTENCY ISSUES

In multi perspective roaming or multi view display, it is easy to encounter problems such as sudden changes in lines, disordered strokes, uneven ink color, and discontinuous blending, which can damage the stability and artistic integrity of the picture. Consistency constraints need to be applied from four levels: geometry, lines, ink color, and rendering.

B. MULTI PERSPECTIVE LINE CONSISTENCY OPTIMIZATION

Establish a perspective normalization line generation mechanism to maintain continuity and stability of contour lines under different perspectives, avoiding sudden appearance or disappearance of lines caused by perspective switching. By cross perspective feature matching, smooth transition, and dynamic weight adjustment, the line style is ensured to be uniform.

C. OPTIMIZATION OF INK CONSISTENCY FROM MULTIPLE PERSPECTIVES

Build a global ink color mapping table to unify the rules of ink color layering, concentration, and transparency from different perspectives, avoiding sudden changes in brightness and color imbalance caused by changes in perspective. Adopting deep linear normalization ensures that the spatial pattern of near rich and far light holds true from any perspective.

D. OPTIMIZATION OF TEMPORAL COHERENCE

To prevent flicker, we apply an Exponentially Weighted Moving Average (EWMA) to stroke positions: $P_t = \lambda \hat{P}_t + (1 - \lambda) P_{t-1}$, where $\hat{P}_t$ is the raw detected position and $\lambda \in [0.6, 0.8]$ is the damping factor. Furthermore, a ‘velocity-based inertia constraint’ is added to the blending diffusion radius to ensure that ink infiltration follows the motion trajectory smoothly without abrupt spatial jumps between frames.

E. REAL TIME ACCELERATION STRATEGY

Adopting GPU acceleration strategies such as hierarchical detail LOD, instantiation rendering, shader optimization, cone clipping, batch drawing, and semi precision computing to reduce computational overhead and improve rendering frame rates. High resolution real-time ink animation output can be achieved on ordinary consumer grade GPUs.

F. OVERALL SYSTEM PERFORMANCE TESTING

Test the system performance in terms of frame rate, resolution, and latency. Under a standard configuration (RTX 3060 GPU, 1080P resolution), the system maintains a stable output of 45–60 fps with a processing latency of less than 25 ms. Testing with a 12-camera array shows that the multi-view synchronization error is controlled within 2 ms, verifying that the proposed method meets the rigorous real-time requirements for immersive exhibitions and virtual live streaming.

G. COMPARATIVE EXPERIMENT AND EFFECT VERIFICATION

Compared with traditional hand drawing and single-view NPR methods, our method shows significant advantages in frame rate and multi-view stability. As detailed in Table 4, our system achieves a 150%–200% increase in rendering speed compared to typical offline NPR pipelines while maintaining 'High' consistency across perspectives.

TABLE 4. Quantitative Real-time Performance Comparison

Method	Frame Rate (FPS)	Multi-view Consistency	Art Fi-delity
Traditional Hand-Drawn	Offline	High	Very High
Single-view NPR	20–25 fps	Medium	Medium
Proposed Method	45–60 fps	High	High

VII. CONCLUSION AND PROSPECT

A. RESEARCH CONCLUSION

(1) An integrated pipeline for multi-view driven ink stylization has been constructed. This framework automates the transition from raw 3D data to stylized visuals, demonstrating an 85% reduction in manual keyframing requirements compared to traditional methods.

(2) Propose a 3D model simplification, line extraction, and stylized mapping method for ink painting art, effectively resolving the contradiction between 3D geometric accuracy and ink painting freehand brushwork, and achieving an artistic effect highly in line with traditional ink painting aesthetics.

(3) Design a five layer real-time ink rendering architecture to achieve collaborative generation of lines, strokes, ink color, blending, and artistic conception, with rich visual layers, natural charm, and long-lasting artistic conception.

(4) Propose optimization strategies for multi perspective consistency and temporal coherence to ensure stable, smooth, and unified animation under continuous motion and multi perspective switching, solving problems such as jitter, abrupt changes, and breakage that are prone to traditional methods.

(5) The prototype system developed can achieve high frame rate and high-resolution real-time ink animation generation on ordinary GPU platforms, with strong practicality, high usability, and good scalability, and has broad application prospects.

B. MAIN INNOVATION POINTS

(1) Combining multi perspective stereoscopic visual dynamic reconstruction with ink animation, creating a new production mode of "real dynamics → 3D models → real-time ink animation".

(2) Establish a four layer ink style mapping mechanism of geometry, lines, strokes, ink color, and artistic conception to achieve a deep integration of art and technology.

(3) Propose a multi perspective collaborative rendering and temporal consistency optimization method to ensure stable and smooth animation with consistent style.

(4) Realize real-time, lightweight, and automated full process, and quickly generate high-quality ink animation without the need for professional hand drawing skills.

C. RESEARCH PROSPECTS

(1) Integrating AI generation models to achieve intelligent recommendation of ink style and automatic generation of artistic conception.

(2) Expand interactive control functions, supporting real-time driving of ink animation changes through gestures, voice, and posture.

(3) Enhance the lightweight deployment capability of mobile and web devices, and expand the scope of applications.

(4) Deepen the generation of themed ink wash animations featuring characters, animals, landscapes, flowers, and birds, and enrich artistic expression.

(5) Promote the large-scale implementation of technology in fields such as digital cultural tourism, virtual humans, immersive exhibitions, and educational science popularization.

AUTHOR CONTRIBUTIONS

Gewu Zhang designed, collected and analyzed the data, and drafted the manuscript. Gewu Zhang conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Gewu Zhang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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