

Research on the Reconstruction of Ancient Weaving Scenes and the Living Transmission of Techniques Based on Virtual Reality (VR)

Ting Guo¹, Velu Perumal¹

¹Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia

Corresponding author: Ting Guo (e-mail: gt2026417@163.com)

ABSTRACT The main challenges to ancient weaving methods include lack of successors, the complicated nature of the methods that are hard to learn intuitively, and prohibitive cost of learning, which results in the imminent loss of this invaluable intangible cultural heritage. The given paper suggests a solution to the restoration of the old weaving scenes and the live transfer of the methods, which are based on the Virtual Reality (VR) technology. To create a knowledge base with 1847 entities and 3,251 relationships, first, field surveys are used to gather data regarding loom structure, process parameters, and videos of activities that inheritors engage in to create the knowledge base. Second, a 1:1 scale loom model is created with 3D modeling technology, with a physics engine to approximate the realistic mechanical properties of warp and weft interlacing. Third, a teaching module is developed as an interactive format, that is, the complex processes are decomposed into 72 operable units and a system of gesture recognition and haptic feedback is incorporated to create an immersive learning experience. Lastly, a multi-user collaborative system is created to assist in remote communication of masters and apprentices. System tests showed that the experimental group only needed 18.3 hours to master the skills, which was 64.9% shorter than the control group's 52.1 hours. The operation accuracy rate reached 92.3%, which was 13.7 percentage points higher than the control group's 78.6%. The cultural cognition score was 87.4 points, which was 1.84 times that of the control group's 47.6 points. This effectively promoted the digital protection and intergenerational inheritance of ancient weaving techniques. The VR training workflow can use electromagnetic or optical-inertial tracking to record hand and body movements during craft learning.

INDEX TERMS virtual reality, ancient weaving, scene reconstruction, haptic interaction, motion tracking

I. INTRODUCTION

THE art of ancient weaving is a significant aspect of the human civilization with rich historical context and cultural implications. The techniques of weaving Yunjin, Shujin and Songjin have developed during thousands of years creating various technical systems and aesthetic styles. But there are extreme challenges to the present transfer of weaving skills: the current generation of the art is aging and has no successors; the procedures are hundreds of steps long, hard to document in full text and images; the students must go through several years of training to learn the fundamentals; and the time and financial investment is so great that young people are not enthusiastic to take part. There are also some rare weaving techniques which have been lost forever due to the death of their heirs and new techniques are desperately required to provide effective protection and spreading of these techniques [1,2].

The technology of virtual reality, with its merits of immersive interaction, the ability to repeat and beat the

restrictions of time and space, can be used to consider new concepts of the inheriting intangible heritage. The VR world is the most effective at re-creating historical scenes and changing the abstract crafts into visual and tactile sensations. Virtual operation allows learners to receive near-realistic training in skills. VR areas, like making ceramics, wood carving techniques, and others, have been applied by domestic and foreign scholars and have yielded results, yet lack a systematic research on the weaving techniques. This paper is devoted to the reconstruction of ancient looms and the passing of practical methods, and develops a VR system to study the practical direction of digital technology in protecting cultural heritage by combining knowledge modeling, scene reconstruction, interactive education, and collaborative platform [3,4].

II. RELATED WORK

Digital preservation of intangible cultural heritage has been a field with fruitful research findings. Technologies includ-

ing 3D scanning, digital modeling and database construction are used by scholars to document and maintain traditional skills. Use of virtual reality in cultural heritage has been slowly changing the aspect of displayed to the aspect of interchange. Museums are employing VR devices to offer the visitor an immersive experience of seeing cultural objects, archaeological sites are recreated in their original form through virtual reconstruction. To preserve the traditional handicrafts, researchers have created skill training systems of ceramic throwing, wood carving, and paper cutting that replicated the actual process of operation in gesture recognition and force feedback devices [5,6]. Knowledge engineering techniques have been applied to the problem of skill preservation, where ontology modeling and semantic networks have been used to organize and describe experience and knowledge of inheritors to create a computable knowledge graph. Remote teaching has become a reality with the emergence of collaborative learning platforms and the distributed architecture allows several users to enter the virtual realm to interact simultaneously. Recent studies have serious flaws, however: the mechanical structures and delicate operational motions involved in weaving techniques make digital restoration much more difficult than other crafts and there are no specialized modeling methods; most systems emphasize presentation over physical interaction, and do not simulate key mechanical behaviour such as the warp tension changes with weft tension, and the teaching module design tends to follow a linear process and fail to offer adaptive guidance to individual learner variations; collaborative To address the above issues, this paper has come up with a holistic solution combining knowledge modeling, physical simulation, intelligent interaction, and collaborative inheritance [7,8].

III. METHODS

A. ACQUISITION AND MODELING OF WEAVING TECHNIQUE KNOWLEDGE

The study chose the Nanjing brocade weaving industry to use as a case study and carried out an eight months follow up study of three inheritors at the national level. This study was approved by the Ethics Committee of Universiti Putra Malaysia, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form. The micro-movements of the hands were captured using high-speed cameras and the variations in body posture were monitored using inertial measurement units to record the motion trajectory of key operations including threading heddles, throwing the shuttle, and inserting the weft. Semi-structured interviews were used to mine implicit knowledge and convert formulae like; tight for five minutes, loose for three minutes into measurable tension control parameters. An ontology model was developed to characterize the logical relationships among weaving processes, the range of values and constraints of 38 process parameters, such as the warp density, weft angle and weft opening/closing amplitude.

TABLE 1. Modeling parameters of key components of the virtual loom

Component Name	Number of polygons	Texture resolution	Physical properties	Collision detection	Rendering optimization
Integrated frame system	18,432	2048×2048	Rigid body constraints	AABB surround box	LOD Level 3 Refinement
Meridian Array	125,600	512×512	Spring mass	Continuous collisions	Instantiation rendering
Shuttle mechanism	6,847	1024×1024	Dynamics simulation	Convex Hull Detection	Occlusion removal
Weft insertion device	9,203	1024×1024	Hinge joint	OBb Enclosed Box	Batch drawing
Flower Book System	15,926	2048×2048	kinematic chain	Grid Precision Detection	Texture compression
Fuselage frame	32,145	4096×4096	Static Mesh	Simplified bounding body	Normal map

A table of action-effect was created where the effects of various forces of operation on the texture of the fabrics were noted. Natural language processing technology was used to extract 273 weaving terms from ancient texts, and combined with physical measurement data to correct historical process flows [9,10]. With the help of the combination of scattered knowledge fragments into a hierarchical knowledge graph, the nodes can be interconnected with semantic relations including ones like: prior to, influence, dependence, etc., to create a base of skill knowledge that consists of 1,847 entities and 3,251 relationships, which allows the correct reconstruction of subsequent virtual scenes.

B. THREE-DIMENSIONAL RECONSTRUCTION OF THE VIRTUAL LOOM SCENE

The point cloud data of a Ming Dynasty jacquard loom was collected using a laser scanner at the position of 0.1 mm with raw data that consisted of 230 million spatial coordinate points. A preliminary mesh representation was created by the Poisson surface reconstruction algorithm and the texture information of the wooden parts was refined with subdivision surface technology. A joint hierarchy structure was developed to determine the six degrees of movement of each component of the moving mechanisms like the heald frame and pedals and was based on forward kinematics. Simulation of the elastic deformation of the warp threads was done with the Havok physics engine, where the Youngs modulus was dynamically adjusted within a range of 5 to 25 GPa to account for varying moisture levels and strain rates, thereby accurately modeling the viscoelastic properties of natural silk. A shader program was created to execute the light and shadow alterations during warp and weft interlacing and dynamically change the diffuse reflection coefficient based on the fabric density. Table 1 shows the modeling parameters of key components of the virtual loom.

This parameter configuration enables the system to maintain visual realism while running smoothly at 90 frames per second on mainstream VR devices. Polygon count control

ensures balanced rendering load, and physical property settings guarantee the accuracy of mechanical feedback for interactive operations.

C. INTERACTIVE TEACHING SYSTEM DESIGN

The system summarizes 72 teaching units of Nanjing brocade weaving into autonomous teaching units. There are three levels in every module, i.e., demonstration animation, operation prompts, and real-time evaluation.

By using a Leap Motion controller detecting finger bending angles and palm angle, it can identify the threadpicking gesture by integrating Leap Motion optical data with IMU finger-tracking to overcome visual occlusions caused by dense threads. The system initiates a grasping gesture when a specific skeletal posture is detected in conjunction with the thumb and forefinger being less than 15 mm apart. An adaptive guidance algorithm is designed, which automatically decreases the difficulty in case of three consecutive operational errors made by a learner, and the entire process is divided into smaller-scale sub-steps. It is fitted with a haptic feedback glove, which reproduces the change of tension in the warp by using a vibration motor, creating a warning vibration when the tension deviates from the standard process threshold of 3.2 Newtons, a value identified through interviews with inheritors as the ideal tension for maintaining silk fabric density and preventing weft distortion. A behavior tree is built to capture the sequence of the operations of the learner and comparing it with the normal process to obtain similarity and producing a multi-dimensional evaluation report containing time deviation, force error, and path accuracy. A challenge system of levels is created; to reach the next stage, learners have to earn 85 points, and the system suggests specific practice assignments and forces based on the weaknesses. Audio explanations which are recorded by inheritors are integrated; on identifying a certain operation, the audio data, namely the technique explanation, is played in time, and the audio content is strictly synchronized with the action nodes, and the error is kept within 200 milliseconds.

D. DEVELOPMENT OF A MULTI-USER COLLABORATIVE INHERITANCE PLATFORM

It is developed on a distributed architecture with the Photon Unity Networking framework, and features a virtual weaving space of up to eight users at once. It uses a hybrid synchronization scheme of client-side prediction and server-side correction, which renders user actions on the client side and transmits status packets to the server at a 50 milliseconds interval. A collision detection algorithm reverse plays frames historically to detect collisions. It is planned to create a role-based division mechanism: the inheritor avatar has annotation permissions, and he can draw arrows in 3D space to mark the most important parts, whereas the apprentice avatar can operate only the unlocked mechanisms in accordance with his/her current learning achievements. Voice spatialization technology is

created, with the volume and reverberation effects varied by the distance and orientation between virtual characters to create the sound field impression of a real workshop. A shared weaving mode is adopted to simulate the traditional dual-person synchronized rhythm of the jacquard loom (the “puller” and the “weaver”). While the system supports up to three users, its primary logic focuses on the real-time coordination between the master (directing from the flower bank) and the apprentice (operating the shuttle), ensuring the preservation of the crafts inherent technical rhythm. The system identifies when the actions of the three parties work in coordination and the team score is calculated. A cloud replay library is created, which automatically logs all the data of the process of each teaching session, so the learners can access and see the details of the demonstrations of the inheritor at any time. It combines text chat and annotation of images. The inheritors are able to take the existing view and mark the critical areas so as to advance them to the entire trainees. The content of the annotations is permanently attached to the point of space in the form of the floating window.

IV. RESULTS AND DISCUSSION

A. SYSTEM FUNCTION IMPLEMENTATION AND PERFORMANCE TESTING

The system functional testing used a mixed black-box and white-box approach to testing, which constructed a test environment of three mainstream devices: HTC Vive Pro, Oculus Quest 2, and Pico 4. The FCAT VR tool was used to continuously monitor the rendering frame rate. Every piece of the loom was inserted into a complicated scene, and a physical simulation was started, and the frame time fluctuation curve was recorded during 30 minutes. The motion capture system was attached to the OptiTrack and the VRPN protocol was used to connect it and the deviation angles of the gesture recognition outputs of the motion library were compared. The distribution of the false recognition rate of 500 samples of operations was statistically tested. A computer program was created that emulates eight virtual clients who concurrently connected to the server and sent random operation commands and measured the round trip latency of network packets. Data packets were captured and analyzed using Wireshark to determine the reason behind loss of packets. A platform of stress testing was constructed and a slow steady tensile force of 0.5-5 Newtons was applied on the warp model. The data on deformation was obtained and compared to the real yarn tensile experiments to determine the percentage deviation of the elastic coefficient. A performance analyzer was installed to monitor the memory assignment, identify possible leakages, as well as gauge the frequency of garbage collection. The number of draw calls and shader compilation time was checked using a GPU profiler.

TABLE 2. Comparison of skill acquisition effects between the two groups of learners

Evaluation indicators	Average value of experimental group	Control group average	Increase	Significance test	Standard deviation
Skill mastery time (hours)	18.3	52.1	Shortened by 64.9%	$p < 0.001$	± 3.2
Operational accuracy (%)	92.3	78.6	Increased by 17.4%	$p < 0.01$	± 4.7
Cultural awareness score (points)	87.4	47.6	An increase of 83.6%	$p < 0.001$	± 6.1
Movement standardization (points)	89.1	81.3	Increased by 9.6%	$p < 0.05$	± 5.4
Number of erroneous operations (times)	12.7	34.8	Reduced by 63.5%	$p < 0.001$	± 7.9
Knowledge retention rate (%)	85.2	69.4	Increased by 22.8%	$p < 0.01$	± 8.3

B. COMPARATIVE ANALYSIS OF LEARNING OUTCOMES

Sixty volunteers with varying skill levels (including 40 complete beginners and 20 semi-skilled apprentices) were recruited and separated into experimental group and control group (30 each) to evaluate the systems effectiveness across different stages of the inheritance lifecycle. Experimental group was taught through a VR system and the control group taught orally through a master-apprentice system. The same inheritor led the two groups. The test comprised three simple skills, which included threading heddles, shuttle throwing and weft insertion. The cumulative time required to complete independently was measured. Blind assessment by the inheritor was used to measure accuracy, comparing the deviation of the warp and weft density, the rate of misaligned patterns and the smoothness of the edges of the final fabric. The measure of cultural awareness was based on a self-administered questionnaire that included 25 questions such as the history of weaving, technological principles, and the names of artifacts, and had a maximum of 100 points. This was a four-week testing period, which was periodically assessed every week. The results are shown in Table 2.

Table 2 shows that the experimental group took only 18.3 hours to master the skills, a 64.9% reduction compared to the control groups 52.1 hours. The operational accuracy rate reached 92.3%, 13.7 percentage points higher than the control groups 78.6%. The cultural cognition score of 87.4 was 1.84 times that of the control groups 47.6. The experimental group made only 12.7 errors, far fewer than the control groups 34.8. After four weeks, the knowledge retention rate remained at 85.2%, demonstrating that the VR system effectively improved learning efficiency and the depth of knowledge internalization. The higher cultural scores are attributed to the integration of multi-source historical archives and 3D exploded views of loom structures, which supplement the traditional oral instruction by providing learners with a macro-perspective of the crafts evolution and complex technical logic.

TABLE 3. Statistics on the Application Effects of Five Intangible Cultural Heritage Units

Application Unit	Number of trainees	Pass rate (%)	Satisfaction rating (score)	Retraining rate (%)	Recommendation intention (%)	Skill upgrade cycle (days)
Jiangsu Yunjin Research Institute	312	94.2	4.6	23.7	96.5	19
Zhejiang Silk Museum	268	91.8	4.5	18.3	94.8	twenty one
Sichuan Shu Brocade and Embroidery Museum	235	89.4	4.4	21.5	92.3	twenty three
Suzhou Song Brocade Heritage Base	201	93.5	4.7	26.4	97.1	18
Guangxi Zhuang Brocade Training Center	184	88.6	4.3	15.8	90.2	25

C. APPLICATION CASES AND USER FEEDBACK

The system was implemented and used in five provincial-level protection units of intangible cultural heritage, including Jiangsu Yunjin Research Institute, Zhejiang Silk Museum, Sichuan Shu Brocade Weaving and Embroidery Museum, Suzhou Song Brocade Weaving Technique Heritage Base and Guangxi Zhuang Brocade Training Center. The training session was between September 2024 and December 2025 and there were 48 training sessions. The sessions were between 20 and 30 participants and took four weeks. There was a satisfaction survey and skills assessment on completion. The questionnaire was designed on a five-point Likert scale, which assessed the usability of the system, the teaching results, cultural experience, and the intention to recommend. A total of 1186 valid questionnaires were received which is a 98.8% response rate. The skills test was also done by those who were inheritors to each unit, who tested the competence of the participants to accomplish simple weaving tasks on their own.

Table 3 shows that out of 1200 trainees, 1103 passed the skills assessment, resulting in an overall pass rate of 91.5%. The average satisfaction score was 4.5, and 96.2% of trainees indicated they would recommend the system to others. The Jiangsu Yunjin Research Institute had the highest number of trainees (312), a pass rate of 94.2%, and the shortest skills improvement period (only 19 days), attributed to the institutes dedicated instructors providing full-time guidance. Retraining data shows that 21.1% of trainees actively applied for advanced courses, reflecting the systems ability to stimulate in-depth learning interest. Five institutions reported that the VR platform overcomes venue limitations, enabling trainees in remote areas to obtain a learning experience equivalent to face-to-face interaction with inheritors of traditional skills.

V. CONCLUSION

The present paper develops a VR-based system of passing down ancient weaving skills. It breaks the spatial and time constraints of technique transmission through knowledge

graph modelling, reconstruction of 3D scenes, interactive teaching design and creation of a multi-user collaborative platform. The system codifies tacit knowledge, decomposes complex processes, and visualizes abstract operations and deals with the pain points of long learning cycles, high resource usage, and low transmission efficiency inherent with oral transmission techniques. The findings of the experiments indicate that the solution drastically reduces the time required to acquire the skills and enhances the precision in operations and cultural awareness. The platform has a high scalability and practical value as seen in application practices by various intangible cultural heritage protection units, and this presents a viable avenue towards the living protection of endangered intangible cultural heritage. Future developments will add additional types of weaving, add the artificial intelligence technology to provide a personalized learning path recommendation, create a lightweight mobile version that will reduce the barrier to entry, consider commercialization models with the cultural tourism industry, and encourage the transfer of techniques between a closed and open system, and between a niche and a mainstream approach.

AUTHOR CONTRIBUTIONS

Conceptualization – Ting Guo and Velu Perumal; methodology – Ting Guo and Velu Perumal; investigation – Ting Guo and Velu Perumal; writing-original draft preparation – Ting Guo and Velu Perumal. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Universiti Putra Malaysia, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

ACKNOWLEDGEMENTS

Not applicable.

REFERENCES

- [1] J. Zhang, H. Li, and J. Zhu, "Digital virtual restoration and effect evaluation of Song brocade small flower loom based on 3D technology," *Journal of Silk*, vol. 62, no. 1, 2025, doi: 10.3969/j.issn.1001-7003.2025.01.004.
- [2] P. Jahoda, Y. Yeganeh, E. Adeli, et al., "PRISM: Progressive Restoration for Scene Graph-Based Image Manipulation," *European Conference on Computer Vision*. Springer, Cham, 2025, doi: 10.1007/978-3-031-91838-4_9.
- [3] F. Shafuda and H. Kondo, "A Multiview-Based Visibility Restoration Method for a Turbid and Occluded Underwater Scene," *Oceanic Engineering, IEEE Journal of*, vol. 50, no. 3, pp. 1906-1929, 2025, doi: 10.1109/JOE.2025.3562630.
- [4] L. Y. Ju, T. Xiao, J. He, et al., "A simulation-enabled slope digital twin for real-time assessment of rain-induced land-slides," *Engineering Geology*, vol. 353, 2025, doi: 10.1016/j.enggeo.2025.108116.
- [5] C. Crone, "Re-Narrating the Past, Producing the Present and Unlocking the Future: Haris al-Quds, a TV-Dramatization of Post-war Syria," *Middle East Critique*, 2023, doi: 10.1080/19436149.2023.2229188.
- [6] C. Marembert, P. Claisse, Floréal Daniel, et al., "Non-invasive characterization of yellow dyes in tapestries of the 18th century: Influence of composition on degradation," *Color Research & Application*, no. 6, 2021, doi: 10.1002/col.22646.
- [7] Y. Kinjo, "Restoration of traditional techniques using digital archive and online, and its inheritance," *Dejitaru Akaibu Gakkaishi*, vol. 5, no. 2, pp. 86-90, 2021, doi: 10.24506/jsda.5.2_86.
- [8] K. Rajabather, S. Abimannan, K. Thirunavukkarasu, et al., "Restoration of Digital Design Using Row and Column Major Parsing a Technique," *Conference paper, Art. no. 000(9194990)*, 2020, doi: 10.1109/CONECCT50063.2020.9198323.
- [9] E. Morozova and V. Anzhela, "Shcherbakova," *Evolution of folk art motifs in domestic printed textiles of the 40-60s of the 20th century. Vestnik slavianskikh kul'tur* [Bulletin of Slavic Cultures], 2022, doi: 10.37816/2073-9567-2022-63-332-347.
- [10] J. Velásquez Runk, "Wounaan Storying as Intervention: Storywork in the Crafting of a Multimodal Illustrated Story Book on People and Birds," *Genealogy*, vol. 5, 2021, doi: 10.3390/genealogy5040091.