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Computer-Aided Design AND APPLICATIONS

Beyond the Boundaries of Reality: A Study on the Development of Digital Interactive Display Simulation System for ICH in Metaverse Scenario

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Abstract. Research on Intangible Cultural Heritage from the perspective of Metaverse mainly focuses on digital preservation, but no system has been formed on how to continuously innovate the means of display and promotion. In order to solve the problems of digital display and promotion of ICH, this paper takes Chinese Han Embroidery as an example and establishes an interactive display simulation system based on the concept of "Metaverse". The system is divided into three layers: data resource layer, context model layer, and resource display layer. The layers are connected by the knowledge base management and Context-aware management subsystem to customize different displays and recommendation information for different users. At the same time, the system builds modules for system management, Chinese Han Embroidery Cultural information management, Chinese Han Embroidery cultural information multimedia display, and user browsing statistics tracking. Through virtual simulation analysis, compared with the traditional Panoramio method, the proposed method has certain advantages in terms of time complexity and the amount of recommended information. The establishment of this system is of great significance to the promotion of digitization in the presentation and dissemination of ICH.

Keywords: Metaverse; Intangible Cultural Heritage; Digital Management; Chinese Han Embroidery;
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1 INTRODUCTION

Intangible Cultural Heritage (ICH) refers to the various traditional cultural expressions that have been passed down from generation to generation by all peoples and are considered an integral part of their cultural heritage, as well as the physical objects and places associated with traditional cultural expressions. However, under the impact of the New Crown epidemic, long-standing problems such as lack of space, disconnection from reality and unsustainability have hindered the release of the cultural and economic value of ICH. In recent years, the development and application of digital technology has, in a sense, expanded the functions of the human brain [1]. The concept of the Metaverse is constantly evolving, and the rise of virtual reality, artificial intelligence, big data, 5G networks and blockchain have provided technical support for the Metaverse. The application of the Metaverse to the field of Intangible Cultural Heritage is just around the corner. The development of the Metaverse in the digital era will change the content, methods, channels and targets of the traditional dissemination of ICH, greatly promoting innovation and transformation in the traditional field and recreating new development scenarios. From exploring, recording, and protecting Intangible Cultural Heritage to using science and technology to promote innovative development, it forms new mechanisms to respond to the opportunities and challenges of Intangible Cultural Heritage dissemination in the post-pandemic era, and has great application value and significance for the protection and innovative development of Intangible Cultural Heritage.

This paper firstly sorts out the current academic hotspots from the perspectives of "Metaverse" and Intangible Cultural Heritage Digitization; Secondly, it discusses the reference model of the Intangible Cultural Heritage digital management and display system, and then explains the key technologies involved in the system from three aspects: the data resource layer, the context model layer and the resource display layer, and designs and implements the management and display system. Finally, through simulation analysis, the system is compared with the traditional Panoramio method for induction and summary.

2 STATE OF THE ART AND THEORETICAL BACKGROUND

2.1 Research Related to the "Metaverse"

In 1992, the famous American author Neal Stephenson mentioned the term "Metaverse" in his book "Snow Crash" **Error! Reference source not found.**. In fact, the conceptual origin of the Metaverse is the virtual world described by American mathematician and computer expert Professor Vernor Vinge in his 1981 book "True Names" as a place where you can enter and experience the real world through brain-computer interface technology **Error! Reference source not found.**. As an emerging concept, the Metaverse has attracted widespread attention from industry, academia, the media, and the public. However, there is no single, clear definition or concept of the Metaverse. Various practitioners, experts, and institutions have provided their own insights into the Metaverse, as shown in Table 1.

Name	*Affiliations*	*Description*
Chen G. Dong H	Peking University	The Metaverse is a virtual world connected and created through science and technology, mapped and interacted with the real world, and has a digital living space of a novel social system.
Zuckerberg M	Facebook	The Metaverse is a world composed of countless interconnected virtual communities where people can meet, work, and entertainment through virtual reality devices (e.g., headphones and eyes), smartphone applications, and other devices.

Baszucki D	Roblox	The Metaverse is a virtual world that connects everyone. Everyone has a virtual identity and can do anything desired. The Metaverse has eight characteristics: identity, friends, immersion, low latency, diversity, anywhere, economy, and civilization.
Redmond E	Nike	The Metaverse spans the physical/digital gap between reality and virtual reality .
Kimber C	Posterscope	The Metaverse is an observable digital universe composed of millions of digital galaxies.
Shabro L	Army Futures Command	The Metaverse is a fuzzy digital hybrid reality. The things and people in the Metaverse are irreplaceable and infinite and are not limited by the traditional physical space.
Kicks P	BITKRAFT Ventures	Metaverse: a lasting and real-time digital world, providing individuals with a series of agency, social existence, and shared space consciousness. It has a wide range of virtual economic systems.
Bellinghausen B	Alissia Spaces	The Metaverse is a bridge between the real and virtual worlds.
Redding N	Redding Futures	The Metaverse is an infinite space where people can do everything physically and still have sensory stimuli such as vision, hearing, touch, and smell.
Piech E	AMP Creative	The Metaverse is a world that no longer pays attention to the difference between our digital avatars and bodies. It is a world where we are surrounded by information (e.g., work, entertainment, and education) using intelligent lenses and brain-computer interface devices. It is the next generation of the internet.
Ning H S	University of Science and Technology Beijing	The general cyberspace (Metaverse) is a unified description of conventional cyberspace and cyber-enabled physical. social, and thinking spaces formed based on ubiquitous connections between things and the deep convergence of spaces[6].
	Amazon	A Metaverse is where everyone and everything in the real world is digitally projected into a cloud world where you can do anything you can do in the real world.
Wikipedia	Encyclopedia	The Metaverse is a collective virtual shared space that consists of a fusion of virtually augmented physical reality and physically persistent virtual space, including the sum of all virtual worlds, augmented reality and the Internet.

Table 1: Different opinions of practitioners and experts on the Metaverse [2-8].

This article focuses on the ICH digital aspects of the Metaverse and analyses it from the perspective of science and technology. From a scientific perspective, the emergence of the Metaverse is the result of the integration of multiple disciplines. The Metaverse will promote the integration and interaction of disciplines such as computer science, mathematics, and the life sciences, innovate scientific paradigms, and promote breakthroughs in traditional systems of philosophy, sociology, and even the humanities. In essence, the Metaverse is an extended concept of cyberspace [9]. From a technical perspective, the Metacosmos is a comprehensive and integrated application of existing IT technologies and represents a new stage in the development of informatization. Therefore, this paper outlines the key technologies involved in the metacosmos from a technical perspective (as shown in Figure 1) and focuses mainly on the design and construction of the ICH management and display system from a digital technology perspective.

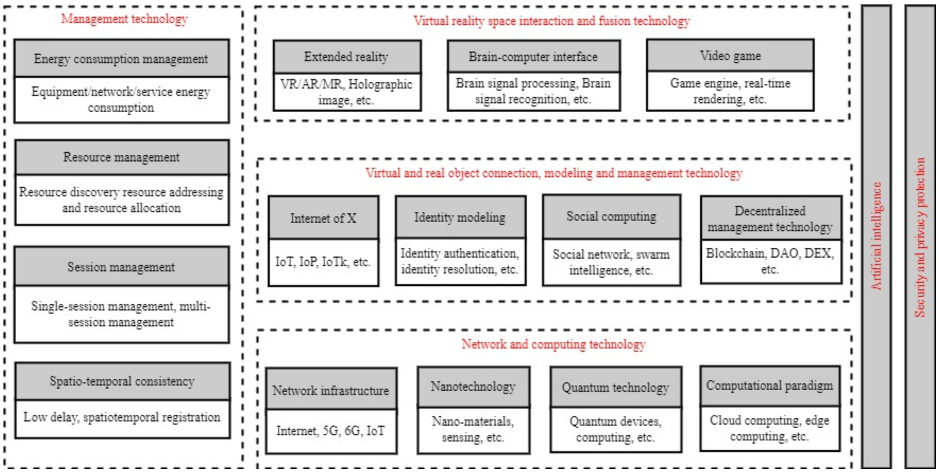

Figure 1: Metaverse technology roadmap.

2.2 Research on the Digitization of Intangible Cultural Heritage

The core issue of Intangible Cultural Heritage preservation under the concept of "Metaverse" is digital exploitation to realize the digital use, display, promotion, and education of ICH.

2.2.1 Digital Representation of Intangible Cultural Heritage

Traditional media for displaying ICH are largely limited to display and dissemination within a specific region, and have many disadvantages compared to digital media. With the advent of multimedia technology, virtual reality, holographic projection, 4G mobile networks, intelligent application terminals and other technical means, the rich and diverse digital media platform provides more forms of expression for the display of ICH [10]. In his research, Cary Karp proposed the construction of a digital virtual museum to provide a platform for the display of Intangible Cultural Heritage [11]; Yuan-wu Shi et al. explored the application of 3D modelling and virtual reality technology in the construction of digital museums of ICH [12]; Marcello Carrozzino et al. discussed the application of virtual reality technology in the digital display of traditional handicrafts [12]; Keiji Yano and Woong Choi used the "Virtual Kyoto" project as an opportunity to use GIS and 3D modelling to construct a virtual float parade display system for the Gion Festival in Kyoto [14]; Muqeem Khan proposed the use of motion sensing technology to build an experiential learning system for intangible cultural heritage in museums **Error! Reference source not found.**; Muqeem Khan and Penny de Byl discussed the application of augmented learning technology in intangible cultural heritage exhibitions [16]; Francisco Guimarães presented the application of augmented reality and cross-media narrative technology in the display of street art in Lisbon [18].

2.2.2 Creation of databases of Intangible Cultural Heritage

Databases are currently one of the most important forms of digital development of Intangible Cultural Heritage, and they are an important means of achieving digital management, use and dissemination of Intangible Cultural Heritage. In their research, Qun-yong Wu and others explored heterogeneous data management strategies from multiple sources of Hakka culture and data service methods, and established a multi-source heterogeneous Hakka cultural data storage strategy based on MongoDB

[19]. Han Youngho and Jang JungSik proposed the concept of constructing and visually displaying Intangible Cultural Heritage information in virtual cyberspace and, in view of the problems with existing ICH databases, suggested that an interactive mechanism should be introduced into the ICH database construction process to visually display the stored ICH information [20]; Despoina Karavia and Andreas Georgopoulos proposed that, based on the spatial characteristics of ICH, the use of geographic information systems can enable the collection, storage, management, calculation, analysis, display and description of data that can be used for the storage and spatial retrieval of intangible cultural heritage information and for analysing the impact of the geographical environment on the morphological evolution of Intangible Cultural Heritage [22]; Renzo Stanley et al. proposed a simple method to transform the redesigned database architecture into a semantic model that can be used for integration and publication, based on a conceptual knowledge discovery (CKDD) approach to database redesign [23].

2.2.3 Digital Dissemination of Intangible Cultural Heritage

The living nature of Intangible Cultural Heritage determines the limits of its information dissemination. Using information technology to disseminate Intangible Cultural Heritage through digital information is not only in line with the current development trend of online cultural dissemination, but also a practical development strategy. In their research, Cristina Caramelo Gomes and Maria Luisa Costa explore user-oriented digital communication strategies for intangible cultural heritage websites [24]; Saifuddin Khalid and Saiful Alam Chowdhury explore the use of social media in the representation and communication of Intangible Cultural Heritage knowledge in Bangladesh [25]; Alessandro Pozzebon and Silvia Calamai discuss the use of smart devices in the dissemination of ICH information [26]; Zhuo Jin discusses the impact of digital media on the transmission of ICH [27]; G. Cozzani et al. using the i-Treasures online learning and dissemination platform initiated by the European Union for the preservation and transfer of ICH knowledge as an example, explore the role of sensor technology, semantic multimedia analysis and other technologies in ICH education and communication, and highlight the main advantages and disadvantages of using innovative technologies in ICH protection and education [28]; Saptarshi Kolay suggested the use of games, animation, and other methods to disseminate traditional Indian handicraft skills to attract and educate young people and promote the revival of traditional handicrafts [29].

In summary, Intangible Cultural Heritage itself has the characteristics of regionality, fluidity, and living nature [30]. Therefore, it is necessary to unearth and present its implicit information [31]. At present, the display of Intangible Cultural Heritage information resources is dominated by the traditional three museums (museums, archives, and libraries), and the display methods are mainly static objects, text, and multimedia descriptions; while the main way of inheriting intangible cultural heritage is mainly oral transmission and family-style intergenerational transmission. The research of scholars at home and abroad on the digital organization and display of Intangible Cultural Heritage mainly focuses on graphic and image descriptions and digital publications. For example, after the digitisation of Intangible Cultural Heritage information resources, 3D modelling or animation conversion can be carried out [32]. However, there are very few applications that use the concept of Metaverse, such as using VR technology to simulate the overall experience of ICH information resources. To solve the above problems, this paper establishes a digital management and display system for Chinese Han Embroidery through modelling. By establishing a knowledge-based management system, different messages can be tailored for different users, thereby achieving the promotion and protection of Chinese Han Embroidery Cultural Heritage.

3 THEORETICAL MODEL REFERENCE

Existing Metaverse research on the technical layout of virtual scenes, social forms, and the reconstruction of situational knowledge provides a reference for the construction of a digital management model for ICH.

3.1 Ontological Data Model

A digital management model for Intangible Cultural Heritage is established to efficiently realize digital Chinese Han Embroidery culture. To simplify the model, a network concept specific to the field of interest is first introduced, and the ontology [33] O is described as follows:

$$O = \{V, E\} \tag{1}$$

Where any node $v \in V$ represents a concept and any edge $e \in E$ represents a certain relationship between two concepts.

- Tag Schema: Considering the ontology set O, the tag schema is defined as a special tuple:

$$\lambda_0 = (A_1, \cdots, A_2, \cdots B_m) \tag{2}$$

Where $A_1, ?, A_n$ are properties of $?_i ? [1, n]$ and $? O = (V, E) ? O, dom(A_i) ? V$, i.e., Ai is the property value of an edge related to multiple ontologies. $B_1, ?, B_m$, are different properties of $\forall_j \in [1, m]$ and $? O = (V, E) ? O, dom(B_j) ? V$, ,i.e., the property values of edges that are not related to multiple ontologies.

In simple terms, ontology properties $A_1, ?, A_n$describe specific concepts in specific information domains, while ontology properties$B_1, ?, B_m$describe the information about Chinese Han Embroidery culture entities collected by some sensors, such as temperature, humidity, etc., or some multimedia information, such as photos, videos, text, simulation models, and other low-level features.

- Tag Semantics. Consider the ontology set O and the tag schema λ_0. The tag semantics of the cultural entity Chinese Han Embroidery is defined as a special tuple:

$$\lambda (CI)_0 = (a_1, \cdots, a_n, b_1, \cdots, b_m) \tag{3}$$

Where $\forall_i \in [1, n]$, $a_i \in O, dom(A_i) \subseteq V$, $\forall_j \in [1, m]$, $? O = (V, E) ? O, dom(B_j) ? V$

Therefore, by using different ontological sets and semantic models for tags, the culture of Chinese Han Embroidery, which focuses on different perspectives, can be formally described.

3.2 Knowledge Base Model

The relationship between different cultural entities and their different attributes can be described using a knowledge base [34]. A cultural knowledge base can be viewed as a graph consisting of many edges and nodes, defined as:

$$G = \{C, R\} \tag{4}$$

Where $\forall_C \in C$ can be a node in the graph can represent a cultural entity in the cultural heritage, an object of interest or an ontological property. $\forall_r \in R$ is an edge in the graph, representing a relationship between different tagged semantics or a connection between objects of interest.

In the knowledge base, each node can be abstracted as a collection of different attributes, and edges can be used to describe the relationship between different attributes. Figure 2 shows an example of a cultural knowledge base model for Chinese embroidery. The example contains a total of 6 nodes (Chinese Han Embroidery, Chinese Han Embroidery exhibition hall, Chinese Han Embroidery History, Chinese Han Embroidery Commodities, Chinese Han Embroidery clothing, Chinese Han Embroidery Multimedia). Different nodes have different attributes, and each edge describes the relationship between the attributes. For example, the Chinese Han Embroidery Exhibition Hall belongs to the Chinese Han Embroidery Category and also to the history of Chinese Han Embroidery. The attributes include information about the geographical location of the museum, famous scenic spots, and historical sites. In addition, the Chinese Han Embroidery Exhibition Hall can collect data in real time through a camera to help managers control the display.

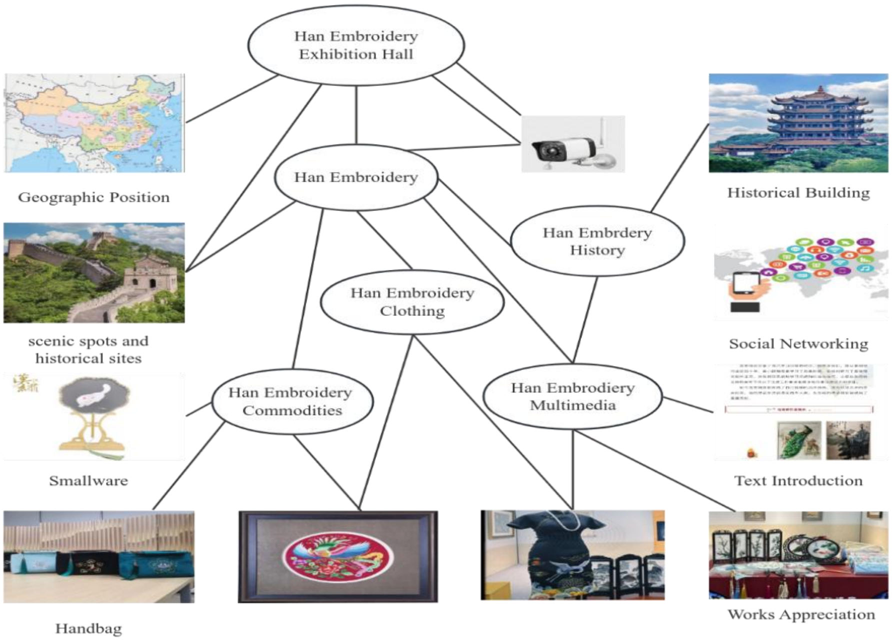

Figure 2: Data model of the knowledge base of Chinese Han Embroidery Culture.

3.3 Context-aware Model

When making relevant recommendations for display systems, the goal is to make the context-dependent target vector as close as possible to the input target vector, i.e., the context-dependent target should be as close as possible to the target it is associated with and as far away as possible from irrelevant targets.

To make the recommended target as effective as possible, important keywords in the context that are highly correlated with the target can be extracted to optimize the target vector [35]. This process can be expressed mathematically as follows:

$$\tilde{t} = X?u' \\ u' = ?(u) \\ ?(u_i) = \begin{cases} u_i, u_i = \text{mean}(u) \\ 0, u_i < \text{mean}(u) \end{cases} \tag{5}$$

Where $\tilde{t}$ is the optimised target vector; u' is the sparse coefficient matrix; $?(u)$ is the step function; and $\text{mean}(?)$ denotes the mean value.

Using the original target vector and the optimized target vector to learn optimization information, the objective function is expressed as:

$$d(\tilde{t}, t) = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} \left(\tilde{t}_i^j - t_i^j \right)^2 + \lambda u_i' \right) \tag{6}$$

Where $?u'$ controls the sparsity of the dilation coefficient matrix.

4 DESIGN OF THE DIGITAL INTERACTIVE DISPLAY SIMULATION SYSTEM FOR INTANGIBLE CULTURAL HERITAGE

The application of the Metaverse to the immersive display of Intangible Cultural Heritage information resources requires entity modelling based on a holistic description of heterogeneous Intangible Cultural Heritage data, combined with various user perceptions and sensor units to map the "Entity-Perception" relationship and develop specific interactive sensing functions to enable immersive scene simulation.

4.1 Overall Framework of the Intangible Cultural Heritage Display Simulation System

Figure 3 shows the system architecture model of the Chinese Han Embroidery digital display simulation system based on the context-aware mechanism. The system consists of three parts: the data resource layer, the context model layer and the resource display layer. The data resource layer includes Intangible Cultural Heritage resource information and user information. Intangible Cultural Heritage resource information comes from the databases of various institutions, such as museums, libraries, archives and other collections; user information includes information such as the user's sense of touch, hearing, vision, body language, facial expressions, and so on. The context model layer is based on the information in the data resource layer. An ICH information resource model is created based on the Intangible Cultural Heritage information and using 3D modelling technology. The interactive design based on user information is combined with the Intangible Cultural Heritage information resource model, and a visualization system for Intangible Cultural Heritage information resources is designed using virtual reality and other technologies. The final resource display layer is based on this Intangible Cultural Heritage information resource visualization system and is used to display and use the resources, including the creation of a 3D virtual space to give users an immersive experience.

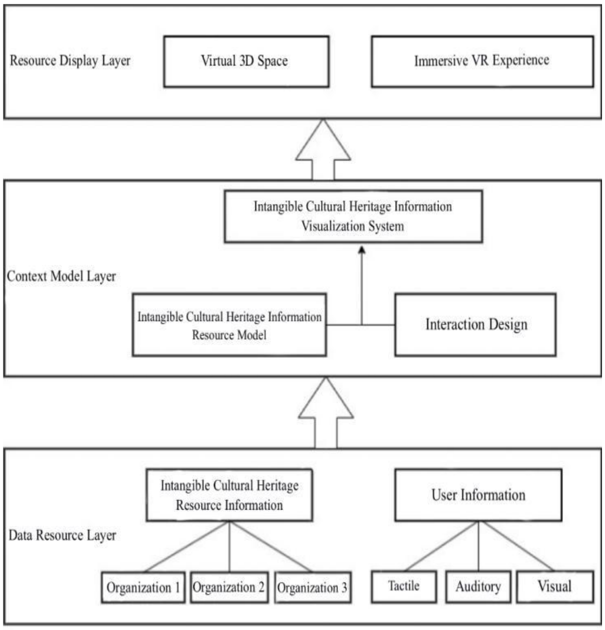

Figure 3: Overall framework for the presentation of information resources on ICH.

4.2 Data Resource Layer

The ICH resource information collected from various institutions and the sensory information provided by users are mostly complex and disordered, including spatio-temporal data such as dynamic trajectory data, time series data, location data, 3D image data and video data. Among them, useful and real information in spatio-temporal data is extracted [36]. At the same time, a description and feedback mechanism for perceiving user behaviour must be established. Therefore, the system data needs to store and process information about both user behaviour and entity resources.

- Behavioural pre-processing.

Tracking and registration technology (a key module in AR technology) can be used to determine user behaviour feedback in entity scenario processing. Tracking and registration technology can achieve seamless integration of virtual information and real scenarios. The system uses image recognition technology to convert the position coordinates of the target image and the position coordinates of the real scene through a transformation matrix. The exact position is obtained by image analysis of landmarks in the real scene [37], thus achieving real-time registration. Experiments have shown that the optical flow tracking (Kamade-Lucas-Tomasi Feature Tracker, KLT) algorithm can be used to complete the target tracking and registration, improve the efficiency of the system’s 3D tracking and registration, and meet the real-time and robustness requirements of the augmented reality system.

Name	*Definition*	*Data Type*	*Is Key*	*Remarks*
Identifier	ID	VarChar (20)	Y	For sorting by entry time
Resource File	File Name	VarChar (20)	N	
Resource Type	Type	VarChar (200)	N	
Resource Title Name	Tittle Name	VarChar (200)	N	Original resource title
Target Audience	Target	VarChar (200)	N	
Source	Source	VarChar (200)	N	Original source of resource
Description	Description	VarChar (200)	N	Resource description
Resource Creation Time	Create Time	VarChar(200)	N	Entry time
Resource Publisher	User Name	VarChar (40)	N	
Resource Creator	Writer	VarChar (40)	N	
Data Format	Format	Int (8)	N	Binary compression
Data Size	Data Sum	VarChar(200)	N	

Table 2: Basic information on Intangible Cultural Heritage resources.

- Storage of entity information.

For ICH entities, the storage of their information is collected from different institutions and stored separately in static databases. In order to dynamically model static data in 3D, technologies such as databases, file systems and distributed data storage are required. Considering that entity resources are usually semantically annotated resources, a mechanism for creating and publishing linked data needs to be established. Table 2 shows the structure of the basic information table for common ICH entity resources.

4.3 Contextual Model Layer

The task of the contextual model layer is to construct an interactive model based on the various heterogeneous information in the lower layer, to integrate it into specific scenarios, and then to establish a visual and sensory interface. As shown in Figure 4, the construction of the Intangible Cultural Heritage information resource model uses 3D modelling technology to digitally process the collected Intangible Cultural Heritage information and build a spatial model based on various data. The system interacts in real time based on human-computer interaction technology and an interaction model. During this process, the system records behavioural data about the process and publishes a view of the relevant scene. Specifically, the context awareness part is used to obtain user behaviour and sensory data. Based on this data, the system matches the resources in the physical resource database and then feeds the scene back to the user.

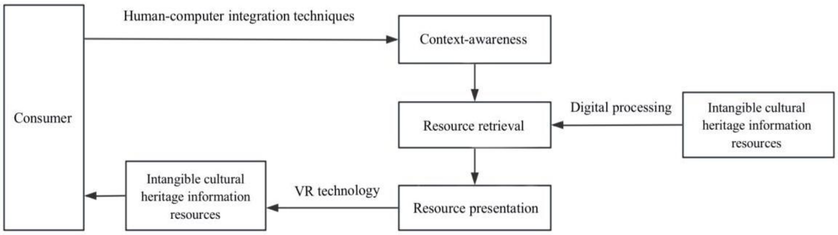

Figure 4: Model for the presentation of ICH information resources.

For the physical modeling of ICH items, this paper adopts the HANDYSCAN 300 3D handheld self-positioning scanner to model the Chinese Han Embroidery, which achieves a resolution of 0.02 mm and a volumetric accuracy of ±0.02 mm. This metrology-grade device projects seven blue laser lines (465 nm wavelength) onto the Embroidery surface at a scanning distance of 300 mm, while four integrated cameras capture modulated patterns at 310,000 measurements per second. The system generates dense point cloud data with 0.08 mm point spacing, enabling real-time mesh reconstruction through its dynamic reference system.

First, the 3D scanner projects the coded raster onto the surface of the target object and captures the modulated raster image, then obtains the point cloud data and x, y, zcoordinates by the algorithm embedded in the scanner, then constructs a 3D mesh model in real time from the 3D point cloud data, then performs image splicing, image alignment, smooth synthesis, and simplified mesh on the real-time data, and the texture mapping was ultimately applied through 4096×4096 pixel UV maps. Finally, the obtained triangular mesh is texture mapped to reconstruct a 3D model with a strong sense of realism. In this paper, the vtkQua dricDecimation mesh iterative simplification algorithm [39] is used to optimize the mesh of the scanned .obj 3D model data,(e.g., silk threads with diameters of 0.1–0.3 mm and stitch spacing of 0.5–2 mm). The selected 0.02mm resolution ensures faithful reproduction of fine textile features while avoiding distortion, making it ideal for delicate cultural heritage artifacts. And the flow of the algorithm is as follows:

- Compute the matrix Q for all initial vertices;
- Select all valid edges;
- For each valid edge $(v1, v2)$, calculate the optimal extraction target ϑ, and the error $\vartheta^T(Q1 + Q2)\vartheta$ is the cost of the extracted edge.
- Put all edges into a heap according to their weights (costs);
- Remove the edge with the lowest cost each time, and then update the cost of all valid edges containing v1. Calculate the initial error matrix Q for each vertex. In the original mesh model, each vertex is the intersection of its surrounding triangular faces. The error of the vertex is defined as the sum of the squares of the distances from the vertex to the plane:

$$\Delta(v) = \Delta\left(\left[v_x\, v_y\, v_z\, 1\right]^T\right) = \sum_{p\in plans(v)} (p^T v)^2 = \sum_{p\in plans(v)} (v^T p)\,(p^T v) = \sum_{p\in plans(v)} v^T\,(pp^T)v = v^T\left(\sum_{p\in plans(v)} K_p\right) \quad (7)$$

Where $p = [a\, b\, c\, d]^T$ represents the plane equation $ax + by + cz + d = 0$, and $a^2 + b^2 + c^2 = 1$, and K^p is the quadratic fundamental error matrix:

$$K^p = pp^T \begin{bmatrix} a^2 & ab & ac & ad \\ ab & b^2 & bc & bd \\ ac & bc & c^2 & cd \\ ad & bd & cd & d^2 \end{bmatrix} \tag{8}$$

Therefore, the initial error of vertex v in the original mesh is $?(v) = 0$. After the edges are contracted, the new vertex error is $?(v_{bar}) = v_{bar}^T Q_{bar} v_{bar}$, The edges that minimize the new vertex error after contraction are selected in turn, and contraction is performed iteratively until the condition is satisfied.

Figure 5: Chinese embroidery work Fishermen's Song.

Take the scanning optimisation of the Chinese Han Embroidery work Fishermen's Song, as an example. According to the aforementioned model, the number of optimised faces is significantly reduced. The size of the model obj format before optimisation is 2.1G, and after optimisation it is 512KB. The test results show that the method of combining 3D scanning and mesh iteration simplification not only enables the rapid modelling of the results of textile intangible cultural heritage projects, but also meets the requirements of realism and fluency in displaying models on mobile screens.

4.4 Resource Display Layer

The resource display layer is a corresponding service provided on the basis of the intangible cultural heritage information resource visualization system. According to Figure 6, users can send command information to the system through human-computer interaction devices and interactively operate according to the system information. At the same time, the system maps the intangible cultural heritage data information, and users can enter the virtual 3D space in real time through wearable devices and fully immerse themselves in the intangible heritage project, including multi-directional triggering of vision, touch, and hearing. This VR experience is more realistic than traditional real-time on-site visits.

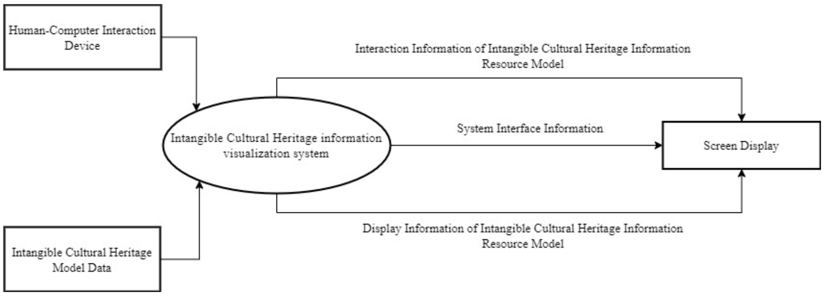

Figure 6: Visual display of ICH information resources based on human-computer interaction.

This paper uses a server and online image recognition technology to enable real-time search of Intangible Cultural Heritage resources. The Fisher Vector Transformation algorithm (ORB-FV algorithm) [40] proposed by Yuchida is used to achieve the online recognition of the system. Figure 7 shows the algorithm flow. The specific algorithm is implemented as follows:

- The ORB descriptor is modelled using a Bernoulli mixture model.

First, let x_t represent the T ORB features extracted from the image $X = \{x_1, ? x_t, ? x_T\}$ where D is the dimension of the feature. Let $\lambda = \{\omega_i, \mu_{id}, i = 1,2,\cdots,, N, d = 1,2,\cdots, D\}$ denote a set of parameters for a multivariate Bernoulli mixture model with N components, and x_{td} denote the d x_t component. Given the parameter set λ, the probability density function of the T features X is given by:

$$p\{X|\lambda\} = \prod_{t=1}^{T} p(x_t|\lambda)$$

$$p\{x_t|\lambda\} = \sum_{i=1}^{N} \omega_i \, p_i(x_t|\lambda)$$

$$p_i\{x_t|\lambda\} = \prod_{d=1}^{D} \mu_{id}^{x_{td}} (1 - \mu_{id})^{1-x_{td}} \tag{9}$$

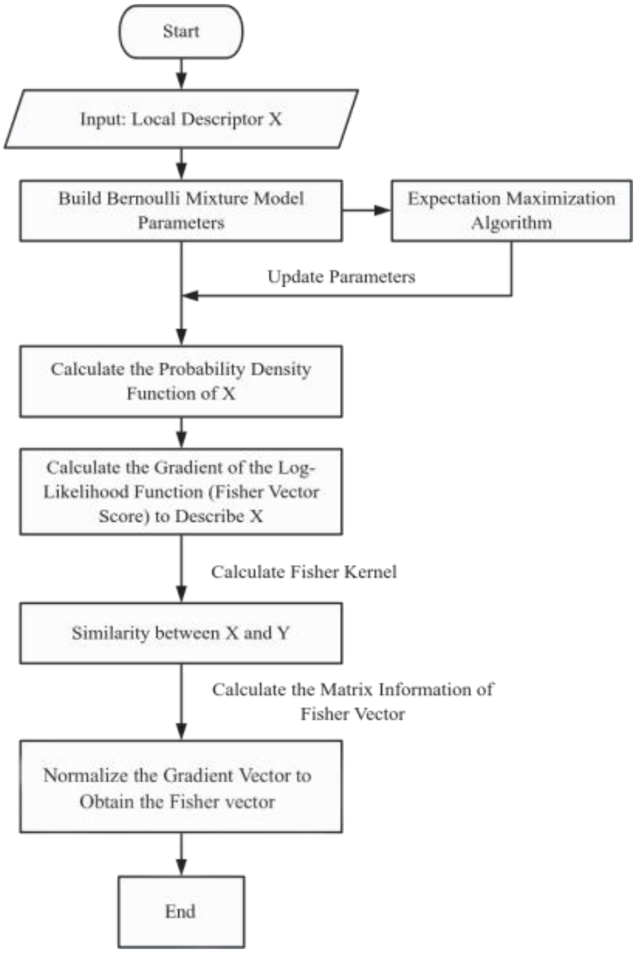

Figure 7: Flowchart of ORB-FV algorithm.

In order to estimate the value of the parameter set λ, given a set of training features $x_1, ? x_s, ? x_S$, the expectation maximization algorithm **Error! Reference source not found.**. In the expectation step, the probability $\gamma_s(i)$ (or the a posteriori probability) of x_s generated by the ith component of the Bernoulli mixture model is:

$$\gamma_s(i) = p(i|x_s, \lambda) = \frac{\omega_i p_i(x_t|\lambda)}{\sum_{i=1}^{N} \omega_j p_j(x_t|\lambda)} \tag{10}$$

In the maximisation step, the parameters are updated:

$$S_i = \sum_{s=1}^{S} \gamma_s(i) \; ; \qquad \omega_i = S_i / S$$
$$\mu_{id} = \frac{1}{S_i} \sum_{s=1}^{S} \gamma_s(i) x_{sd} \tag{11}$$

The parameters ω_i are initialised using $1/N$, and μ_{id} has a uniform distribution u(0.25,0.75).

- The Fisher vector is then obtained by taking the gradient vector of the likelihood function of this function.

Let $X = \{x_1, ? x_t, ? x_T\}$ be the T observed samples, and $x_t \in X$. Let μ_λ be the probability density function that models the generation process of the elements in X, where $\lambda = [\lambda_1, \lambda_2, \cdots, \lambda_M]' \in R^M$, representing the M vectors with parameters $u_?$. Jaakkola T S et al [41]. proposed to use the gradient of the log-likelihood function G_λ^x to describe X, G_λ^x is called the Fisher score:

$$G_\lambda^x = \frac{1}{T} \nabla_\lambda \mathcal{L}(X|\lambda) \tag{12}$$

Where $?(X|?)$ is the log-likelihood function:

$$\mathcal{L}(X|\lambda) = \log(X|\lambda) \tag{13}$$

This gradient describes how the parameters of the generative model $u_?$can be modified to better fit the data X. Since $G_\lambda^x \in R^M$, the dimension of G_λ^x depends only on the number of parameters M in λ and not on the sample size T.

Jaakkola and Haussler proposed in 1998 to use the Fisher Kernel to measure the similarity between two samples X and Y, which is defined as follows:

$$K(X, Y) = G_?^X F_?^{?1} G_?^Y \tag{14}$$

Where $F_?$ is the Fisher information matrix of $p(X|\lambda)$

$$F_\lambda = E_X\left[\nabla_\lambda \mathcal{L}(X|\lambda) \nabla_\lambda \mathcal{L}(X|\lambda)^T\right] \tag{15}$$

Since F_λ^{-1} is positive semidefinite and symmetric, it has a Cholesky decomposition $F_\lambda^{-1} = L_\lambda^T L_\lambda$. The Fisher kernel is therefore rewritten as the dot product between the normalised gradient vector $\mathcal{G}_?^x$ and:

$$\mathcal{G}_\lambda^x = L_\lambda G_\lambda^X \tag{16}$$

Given the Fisher vector $\mathcal{Z} = \mathcal{G}_\lambda^x$, normalise according to the in-frame normalisation method:

$$f(z) = \text{sign}(z)|z|^a \tag{17}$$

In the experiment, set to $a = 0.5$. The normalisation of $f(z)$ gives the final Fisher vector representation of the set of binary features. The resulting Fisher vector contains feature information for the entire image, so we use this vector to represent an image. Image recognition is converted from matching a large number of feature vectors to matching a Fisher vector, which greatly reduces matching time

5 REALISATION OF THE ICH INTERACTIVE DISPLAY SIMULATION SYSTEM DESIGN

Based on the above analysis, the display simulation system developed this time is a Java web project based on SSH, and the focus is on building the SSH (Struts1+ Hibernate3+Spring2) framework [43].

5.1 System Management Module

The system management module is an essential part of a complete and secure information management system. It is mainly used to prevent malicious logins by illegal users from modifying or even destroying system data, causing irreparable economic loss to the operator. The system administrator can maintain the system by managing users' login information, which greatly improves the security and stability of the system. This module mainly uses the flexible application of HQ statements. The functions of adding, retrieving, and deleting user information can be achieved by directly adding, retrieving, and deleting data in the tb_manager table to maintain the system. Adding users can be achieved by using the insertManager() method, querying users by calling the queryManager() method, and deleting users by calling the deleteManager() method.

5.2 Chinese Han Embroidery Cultural Data Management Module

Based on the needs analysis and overall design, the Chinese Han Embroidery Cultural data project should include: types of Chinese Han Embroidery, names, production time, pattern characteristics, customs, legends, heirs, remarks, etc. The service of the Chinese Han Embroidery cultural data management module is designed for two types of users: system administrators and ordinary users. Chinese Han Embroidery Cultural data management module permission control System administrators can enter and modify Chinese Han Embroidery data, and then directly publish it to the website; ordinary users can enter and modify Chinese Han Embroidery Cultural data, but must wait for the system administrator to review it before it can be published to the website.

5.3 Multimedia Display Function Module for Chinese Han Embroidery Cultural Data

According to the characteristics of traditional festivals, the multimedia display function module for traditional festival cultural data can select relevant texts, pictures, audio, video, and other materials, combine them organically, and finally display them on the web page to achieve the multimedia display function of traditional Chinese Han Embroidery. This module should also realize the function of searching Chinese Han Embroidery Cultural data by category, supporting at least single and comprehensive searches for several items such as type, name, production time, pattern characteristics, etiquette, legends, allusions, and heirs. This feature is intended for administrators and ordinary users, and will be used primarily by ordinary users. Access control is not required.

6 EXPERIMENTAL SIMULATION

The steps involved in using a digital interactive display simulation system to display Chinese Han Embroidery mainly include (a) 3D scanning. A high-precision 3D scanning device is used to scan the Chinese Han Embroidery work. (b) Data processing and optimization. The raw data obtained from scanning is imported into professional data processing software, and the data must undergo a series of processes, including noise removal, filling in the missing parts created during scanning, and data smoothing and optimization. (c) 3D modelling. This step requires a high level of Metaverse expertise. A meticulous modelling process ensures that the digital model accurately reflects the original appearance of Chinese Han Embroidery, including its unique embroidery techniques and designs. (d) Material Rendering. To make the 3D model more realistic, appropriate materials and textures must be applied to it. This step simulates the material properties unique to Chinese Han Embroidery, such as the luster, colour, and texture of silk, as well as other details such as the reflective properties of thread. Advanced rendering techniques can make digitally recreated Chinese Han Embroidery visually comparable to the real thing, as shown in Figure 8, which pre-scan and render traditional Chinese Han Embroidery patterns. The material rendering process employed Substance Painter's PBR pipeline, producing texture maps in 4K resolution (3840×2160 pixels). (e) Interactive design. To enhance the audience's sense of participation and experience, an interactive system can be used to allow users to interact with 3D models via a touchscreen or VR equipment as demonstrated in Figure 10, users can select avatars representing diverse demographics, including elderly persons (both male and female), adults, children, and infants, ensuring accessibility for all potential users. Through touchscreen or VR interfaces (Figures 11-12), users can employ mouse controls for 360-degree model rotation, utilize touchscreen gestures for zooming, or engage in full-body motion capture through VR devices. Participants can not only rotate and zoom 3D models to examine embroidery details from any angle, but also visualize how the traditional designs would appear on different body types and age groups. This interactive display method not only enhances the audience's sense of immersion but also modernizes and technologizes the display of Chinese embroidery art.

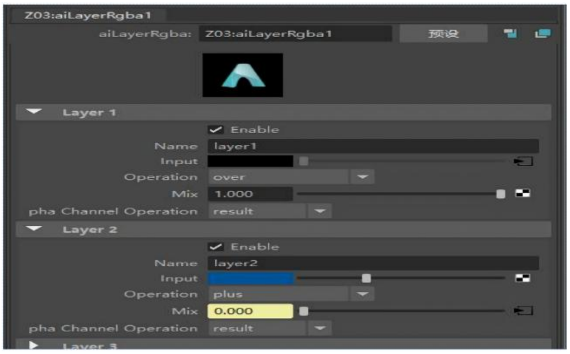

Figure 8: 3D modeling rendering node.

Figure 9: Virtual character tailoring.

The virtual simulation can collect digital data on Chinese Han Embroidery, including data models such as photographs, videos, text descriptions, and handicraft products. Then, various types of data are stored in a knowledge base using an annotation scheme, and a SQL database is used to create field information for cultural relics (products), such as location information (the latitude and longitude of a physical cultural relic) and evaluation information (the evaluation of the cultural relic by previous user visits and consumption content). The content of each field can be null (e.g., some crafts do not have latitude and longitude information).

Figure 10: Effect display.

Figure 11: Virtual character displaying Chinese Han Embroidery clothing.

At the same time, fields can be added or deleted as required. Several database tables are linked by relationships to form a knowledge base. To simplify the model, two evaluation metrics are introduced into the system: time complexity $t_c$and the number of task-related goals r_c. The Panoramio method proposed in the reference [44] is used as a comparison method to test the two evaluation metrics with the method proposed in this paper, and selected the Panoramio method as our benchmark for three key reasons: (a) its proven reliability in geotagged cultural content management, (b) comparable data structures for heritage documentation, and (c) established evaluation protocols for temporal performance analysis, as shown in Figures 13-14.

The results show that the virtual simulation method proposed in this paper has a slight advantage in time complexity compared to the Panoramio method, reducing the time consumption by about 10%. In terms of the number of task-related goals, the method proposed in this paper can provide more information related to user needs, and the amount of information is 1.2 to 1.5 times that of the Panoramio method.

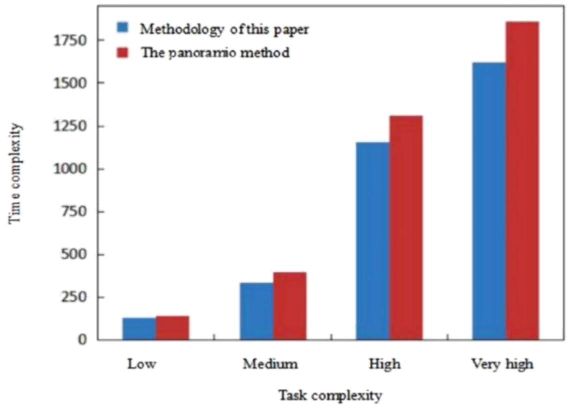

Figure 12: Comparison results of time complexity.

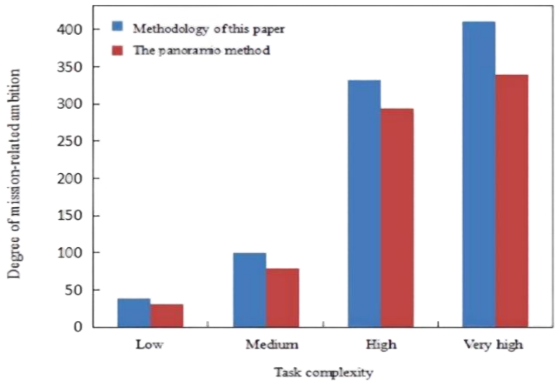

Figure 13: Comparative results of mission-related target numbers.

7 CONCLUSIONS

Traditional Chinese Han embroidery faces a great dilemma in being passed down from generation to generation due to its high production cost and low practicality. To this end, this paper uses ontology and knowledge base data models to digitally generate the culture of Chinese Han Embroidery from the perspective of the "Metaverse". A digital management system for Chinese Han Embroidery is established based on a context-aware mechanism.

The data resource layer provides a rich source of data for the digital display of Chinese Han Embroidery; the context model layer uses knowledge base management systems, context management systems, etc. to provide targeted application management for each user; and the resource display layer takes user experience as the starting point to provide users with specific service functions. The system has built modules such as system management, Chinese Han Embroidery Cultural data management, multimedia display functions of Chinese Han Embroidery cultural data, and tracking and statistics functions for users browsing the website. Through the analysis of the virtual simulation experiment of Chinese Han Embroidery, it is found that the time complexity of the method proposed in this paper is reduced by about 10% compared with the Panoramio method.

As a future research direction, the system can be applied to mobile terminals to provide service requests for different users faster and more conveniently. In addition, the digital display results of

Chinese Han Embroidery Culture can be enriched by combining technologies such as big data, data mining, and the Internet of Things to provide users with richer recommendations for displaying Intangible Cultural Heritage.

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REFERENCES

[1] Meiqun, H.; Xiaoqin, Z.: Review and Prospect of the Digital Inheritance of Intangible Cultural Heritage in the Past Twenty Years, Journal of South-Central University for Nationalities (Humanities and Social Sciences Edition), 42(01), 2022, 65-74+184. http://doi.org/10.19898/j.cnki.42-1704/C.2022.0109

[2] What is the Metaverse of the recent fire? https://baijiahao.baidu.com/s?id=1710776745437385158&wfr=spider&for=pc, CNR.

[3] O'Brien, M.; Chan, K.: Explainer: What is the Metaverse and how will it work? https://apnews.com/article/meta-facebook-explaining-the-metaverse-f57e01cd5739840945e89fd668b0fa27, AP News.

[4] LinX.: Metaverse: What? Why? When?, https://www.solactive.com/Metaverse-what-why-when/, Solactive.

[5] Hackl, C.: Defining the metaverse today, https://www.forbes.com/sites/cathyhackl/2021/05/02/defining-the-metaverse-today/?sh=8204e5964485, Forbes.

[6] Ning, H.-S.; Ye, X.-Z.; Bouras, M.-A.; Dawei, W.; Daneshmand, M.: General cyberspace. Cyberspace and cyber-enabled spaces, IEEE Internet Things J, 5（3）, 2018, 1843. http://doi.org/ 10.1109/JIOT.2018.2815535

[7] Amazon cloud technology helps you explore the metaverse, https://aws.amazon.com/cn/campaigns/metaverse/Wikipedia, Amazon Web Services.

[8] Metaverse, https://encyclopedia.thefreedictionary.com/metaverse, Wikipedia Encyclopedia.

[9] Siddiqi, M.-A.; Yu, H.; Jung, J.: 5G ultra-reliable low-latency communication implementation challenges and operational issues with IoT devices. Electronics, 8(9), 2019, 981. https://doi.org/10.3390/electronics8090981

[10] Xu, Z.: Research on digital display media of intangible cultural heritage, Packaging Engineering, (10), 2015, 20-23. https://doi.org/10.19554/j.cnki.1001-3563.2015.10.007

[11] Karp, C.: Digital Heritage in Digital Museums, Museum International, 6（1-4）, 2004, 157-162. https://doi.org/10.1111/j.1350-0775.2004.00457.x

[12] Shi, Y.-W.; Hao, J.-F.; Sun, S.-Q.: The Digital Protection of Intangible Cultural Heritage-The Construction of Digital Museum, Proceedings of the International Conference on Computer-Aided Industrial Design and Conceptual Design, 2008, 1196-1199. https://doi.org/10.1109/CAIDCD.2008.4730777

[13] Carrozzino, M.; Scucces, A.; Leonardi, R.; Evangelista, C.; Bergamasco, M.: Virtually preserving the intangible heritage of artistic handicraft, Journal of Cultural Heritage, 12（1）, 2011, 82-87. https://doi.org/10.1016/j.culher.2010.10.002

[14] Yano, K.; Nakaya, T.; Isoda, Y.; Takase, Y.; Kawasumi, T.; Matsuoka, K.; Seto, T.; Kawahara, D.; Tsukamoto, A.; Inoue, M.; Kirimura, T.: Virtual Kyoto: 4DGIS Comprising Spatial and Temporal Dimensions, Journal of Geography, 117（2）, 2008, 464-478. https://doi.org/10.5026/jgeography.117.464

[15] Choi, W.; Fukumori, T.; Furukawa, K.; Hachimura, K.; Nishiura, T.; Yano, K.: Virtual Yamahoko parade in virtual Kyoto, SIGGRAPH '10: ACM SIGGRAPH 2010 Posters, 2010, 1. https://doi.org/10.1145/1836845.1837001

[16] Khan, M.: MUSE: Understanding Traditional Dances, IEEE Virtual Reality Conference, 2014, 173-174. https://doi.org/10.1109/VR.2014.6802107

[17] Khan, M.; Byl, P.: Preserving our Past with Toys of the Future, ASCILITE 2011 Proceedings: Changing demands, changing directions, 2011, 718-728. http://www.ascilite.org/conferences/hobart11/downloads/ProceedingsV3.pdf

[18] Guimarães, F.; Figueiredo, M.; Rodrigues, J.: Augmented Reality and Storytelling in heritage application in public gardens: Caloust Gulbenkian Foundation Garden, Digital Heritage, 2015, IEEE, 1, 2015, 317-320. https://doi.org/10.1109/DigitalHeritage.2015.7413891

[19] Wu, Q.; Chen, C.; Jiang, Y.: Multi-source heterogeneous Hakka culture heritage data management based on MongoDB, 2016 Fifth International Conference on Agro-Geoinformatics (Agro-Geoinformatics), IEEE, 2016, 1-6. https://doi.org/10.1109/Agro-Geoinformatics.2016.7577628

[20] Youngho, H.; Jung Sik, J.: A Study on the Cyber Museum Organization System for Intangible Cultural Properties II Focused on the Information system and classification code anger-Focusing on the Exhibition Space, Exhibition Method and Expression Specialty, Korean Institute of Interior Design Journal, （40）, 2003, 165-171.

[21] Youngho, H.; Jung Sik, J.: A study on the Cyber Museum Organization System for Intangible Cultural Properties III-Focused on the Chungnam Province, Korean Institute of Interior Design Journal, （6）, 2004, 179-186.

[22] Karavia, D.; Georgopoulos, A.: Placing Intangible Cultural Heritage, Digital Heritage International Congress, 2013, 675-678. https://doi.org/10.1109/DigitalHeritage.2013.6743815

[23] Stanley, R.; Astudillo, H.; Codocedo, V.; Napol, A.: A Conceptual-KDD Approach and its Application to Cultural Heritage, The Tenth International Conference on Concept Lattices and Their Applications, 2013, 163-174.

[24] Gomes, C.-C.; Costa, M.-L.: Intangible Cultural Heritage and Digital Communications, Rebelo F, Soares M. Advances in Ergonomics In Design, Usability & Special Populations: Part II, AHFE Conference, 2014, 271-283. https://doi.org/10.54941/ahfe1001241

[25] Khalid, S.; Chowdhury, S.-A.: Representation and Dissemination of Intangible Cultural Heritage of Bangladesh through Social Media, Proceeding Book: 4th Interdisciplinary Tourism Research Conference. Anatolia: An International Journal of Tourism and Hospitality Research, 2016, 194-203. https://doi.org/10.1080/13032917.2017.1414438

[26] Pozzebon, A.; Calamai, S.: Smart devices for Intangible Cultural Heritage fruition, Digital Heritage 2015, IEEE, 2015, 333-336. https://doi.org/10.1109/DigitalHeritage.2015.7413895

[27] Zhou, J.: The Influence of the Intangible Cultural Heritage About propagation medium in the Big data era, MATEC Web of Conferences. EDP Sciences, 2016, 63. https://doi.org/10.1051/matecconf/20166304022

[28] Cozzani, G.; Pozzi, F.; Dagnino, F.-M.; Katos, A.-V.; Katsouli, E.-F.: Innovative technologies for intangible cultural heritage education and preservation: the case of i-Treasures, Personal & Ubiquitous Computing, 2016, 1-13. https://doi.org/10.1007/s00779-016-0991-z

[29] Kolay, S.: Cultural Heritage Preservation of Traditional Indian Art through Virtual New-media, Procedia-Social and Behavioral Sciences, 225, 2016, 309-320. https://doi.org/10.1016/j.sbspro.2016.06.030

[30] Tan, G.-X.; Sun, C.-M.: Digital protection and dissemination of intangible cultural heritage under the theory of information space, Journal of Southwest University for Nationalities (Humanities and Social Sciences Edition), 34 (6), 2013, 179-184.

[31] Cheng, X.-F.; Bi, C.-W.; Li, C.-L.: Research on the association of tacit knowledge of dance intangible cultural heritage based on SNA, Library and Information Service, 60(2), 2016, 30-36. https://doi.org/10.13266/j.issn.0252-3116.2016.02.004

[32] Zhang, L.; Zhu, R.; Niu, C.; Shao, S.-Y.: Research on three-dimensional digital protection and dissemination of intangible cultural heritage—taking Huishan clay figurines as an example, Decoration, (8), 2016, 126-127. https://doi.org/10.16272/j.cnki.cn11-1392/j.2016.08.034

[33] Anon.: Information Technology: findings on information technology reported by investigators at St. Petersburg State University (A method of semi-automated ontology population from multiple semi-structured data sources), Computer Technology Journal, 2020, 184.

[34] He, Z.-T.; Li, X.-N.; Yue, Q.; Zhao, F.-W.: A knowledge base engine based on emergency management of emergencies, Information Technology, 38(9), 2014, 60-62. https://doi.org/10.13274/j.cnki.hdzj.2014.09.071

[35] Sarker, I.-H.; Kayes, A.-S.-M.: ABC-RuleMiner: user behavioral rule-based machine learning method for context-aware intelligent services, Journal of Network and Computer Applications, 2020, 168. https://doi.org/10.1016/j.jnca.2020.102762

[36] Mo, J.-Q.: Research on the application of VR scenes in physical bookstores, Nanjing University, Nanjing, 2017.

[37] Chen, Z.-C.; Chen, J.; Yan, L.; Zhang, Y.-C.: Unity3D-based Mobile Optical Experiment Platform for Augmented Reality, Journal of Computer Applications, 35(S2), 2015, 194-199.

[38] He, F.-B.; Liang, Y.-D.; Zhang, H.-Z.; Wang, K.-X.; Wu, T.: Application of Augmented Reality Technology in Turning Machining Training Teaching, Experiment Technology, and Management, 34(3), 2017, 127-129, 150. https://doi.org/10.16791/j.cnki.sjg.2017.03.032

[39] Yirci, M.; Ulusoy, I.: A Comparative Study on Polygonal Mesh Simplification Algorithms, Signal Processing and Communications Applications Conference, 2009, SIU 2009, IEEE 17th, Antalya, Turkey, IEEE, 2009, 736-739. https://doi.org/10.1109/SIU.2009.5136501

[40] Uchida, Y.; Sakazawa, S.; Satoh, S.: Image Retrieval with Fisher Vectors of Binary Features, ITE Transactions on Media Technology and Applications, 4(4), 2016, 23-28. https://doi.org/10.48550/arXiv.1609.08291

[41] Perronnin. F.; Mensink. T.: Improving the Fisher Kernel for Large-scale Image Classification, European Conference on Computer Vision, Berlin, Heidelberg: Springer-Verlag, 2010, 143-156. https://doi.org/10.1007/978-3-642-15561-1_11

[42] Jaakkola, T.-S.; Haussler, D.: Exploiting Generative Models in Discriminative Classifiers, Advances in Neural Information Processing Systems (S1049-5258), 11(11), 1998, 487-493.

[43] Adomavicius, G.; Sankaranarayanan, R.; Sen, S.; Tuzhilin, A.: Incorporating contextual information in recommender systems using a multidimensional approach, ACM Transactions on Information Systems (TOIS), 23(1), 2005, 103-145. https://doi.org/10.1145/1055709.1055714

[44] Lu, H.-P.: Detailed explanation of JSP development technology, Chemical Industry Press, Beijing, 2010.