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Using PID-BP Digital Virtual Reality for Non-Heritage Protection: Recognition and Assessment

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Abstract

The objective of this paper is to address the issues of low accuracy and slow real-time performance in the existing algorithm for digitally protecting and evaluating non-heritage culture. To achieve this, we propose an improved method for the identification and assessment of non-heritage digital protection by optimizing the BP neural network using the PID search algorithm. This method aims to enhance the precision and real-time capabilities of the algorithm. We extract a set of feature vectors from the digital protection process of non-heritage culture and construct a recognition and evaluation system. The PID search algorithm is employed to optimize the BP neural network, which helps in establishing a mapping relationship between the feature vectors and the assessment values of non-heritage digital protection. We apply this method to the digital protection of non-heritage culture in Dali Xizhou as a case study. The results show that our method significantly improves the accuracy and real-time performance of the assessment compared to traditional BP and other optimized BP network models. This study provides a novel and effective approach to the digital protection of non-heritage culture.

Keywords: Digital Ecology; PID Search Algorithm; BP Neural Network; Digital Preservation of Non-Heritage.

1. Introduction

Recently, the Chinese government has prioritized the establishment of a strong digital ecosystem and implemented many laws to promote digitization, particularly in safeguarding intangible cultural treasures [1]. When addressing the challenge of preserving intangible cultural heritage, digital technology plays a pivotal role in both protection and optimization, offering innovative solutions that not only safeguard such heritage but also enhance public understanding and appreciation of diverse cultures, thereby preserving cultural diversity and facilitating cross-cultural research [2]. The research on identification and assessment methods for digital protection of non-heritage (NRH) culture aligns with the "Digital China" initiative, providing comprehensive and practical suggestions to NRH cultural protectors while improving the optimization of digital protection techniques [3].

The present study focuses on the digital preservation of non-heritage culture, specifically exploring its digital design, appraisal, and application [4]. Gireesh [5] introduced the concept of non-heritage 4D modeling, integrating 3D modeling with temporal dimensions to emphasize key technologies for digital library construction. Li et al. [6] sought to enhance museum propaganda by integrating 3D, VR, and AR technologies to create interactive online museums, thereby boosting public engagement. Skublewska-Paszkowska et al. [7] employed artificial intelligence to analyze the movements, emotions, and voices of Greek dancers, enabling immersive content retrieval and dance movement learning for cultural

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institutions. Singhania & Mishra [8] utilized 3D virtual reconstruction to allow tourists to digitally engage with Persian diving traditions, establishing a framework for intangible heritage safeguarding. He & Wen [9] explored digital distribution strategies for non-heritage culture in the new media era, while Xie et al. [10] investigated the fusion of artificial intelligence and non-heritage tourism. As AI algorithms advance, machine learning techniques like clustering, neural networks, and deep learning are increasingly applied to NRH digital asset protection, yet a critical analysis reveals notable gaps: current preservation relies heavily on traditional digital photography [11], with insufficient exploration of emerging technologies (e.g., AI, VR, blockchain) within the digital ecosystem. Additionally, assessment algorithms for NRH digital protection remain predominantly qualitative, lacking quantitative comparative analysis [12], and failing to establish a systematic, scientific, and objective evaluation index system [12, 13].

To address these gaps, this paper proposes a method to improve identification and assessment algorithms for NRH digital protection by optimizing neural network structural parameters through an intelligent PID search algorithm [14]. To address the issue, we propose a model that utilizes the optimization of the BP neural network through the PID search algorithm, where $K_p \cdot K_i$ and K_d denote the proportional, integral, and derivative coefficients, respectively. The PID algorithm calculates the control quantity based on the error $e(t)$, which is the difference between the target and actual values. Focused on safeguarding NRH's digital integrity within the digital ecosystem, we analyze the NRH digital protection process to develop an identification and assessment scheme. The proposed model leverages PID algorithm-optimized BP neural networks to address the limitations of existing qualitative assessment and technical gaps, validated through a case study on NRH digital protection in Dali, Yunnan Province, to verify the model's accuracy and efficiency in quantitative evaluation. This approach integrates adaptive optimization with neural networks to establish a systematic, data-driven assessment framework, bridging the divide between traditional preservation methods and emerging intelligent technologies.

The paper is structured as follows: Part 2 elaborates on the digital ecology framework for NRH protection and the construction of identification feature vectors; Part 3 details the PID-BP neural network optimization model, including algorithm principles and parameter tuning mechanisms; Part 4 presents the case study in Dali, covering data collection, model application processes, and experimental setup; Part 5 conducts comparative analysis of experimental results, including accuracy verification and performance comparisons with traditional methods; and Part 6 summarizes the research findings, highlights practical implications, and outlines future research directions for expanding the model's applicability in diverse NRH protection scenarios.

2. Identification and Evaluation Program

2.1. Problem Analysis

- ***Digital Ecology***

Digital ecology usually refers to a complex system containing many aspects such as economy, society, and environment, which is formed based on digital technology and promotes connection, interaction, and synergy among various subjects through the flow and processing of data [15]. It emphasizes the organic combination and ecological development of elements such as technology, data, platforms, applications, and services in the process of digital transformation, as shown in Figure 1.

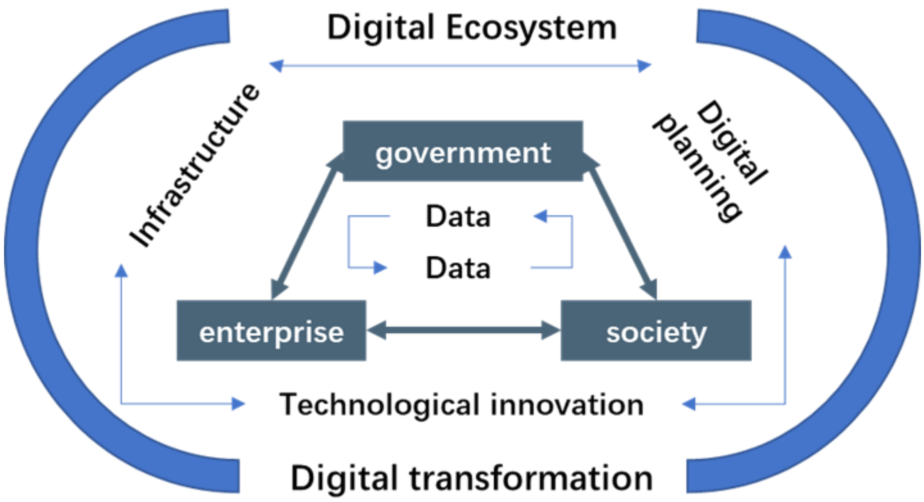


Figure 1. Digital ecology

- ***Digitization of Non-Heritage***

Digitization of intangible heritage refers to the process of collecting, recording, storing, disseminating, and recreating intangible cultural heritage by using digital technological means (Figure 2). This method can not only protect traditional ICH but also transmit it innovatively, opening up new paths for the protection and development of ICH [15, 16].

Figure 2. Digitization of non-legacy

The steps of digital preservation include 1) digital resource acquisition and inscription; 2) 3D modeling and virtual reality technology; 3) establishment of a digital platform; and 4) digital dissemination and innovative development, as shown in Figure 3 [17].

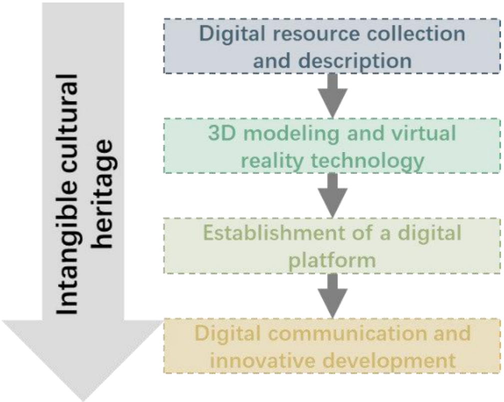


Figure 3. Process of digital preservation of NRH

- ***The Case of Digital Preservation of Non-Heritage in Dali Xizhou***

The Dali Bai Autonomous Prefecture is home to a large number of Bai people, so the region's culture is mainly dominated by Bai culture. The town of Xizhou in Dali is the area with the largest number of Bai inhabitants, and it is an important source for the development of Yunnan Yunnan culture, as well as an important birthplace of Bai culture. Dali Xizhou has become a highly representative non-heritage protection area in Dali because of its Bai cultural characteristics [18].

Dali Xizhou NRLs include folklore NRLs, technical NRLs, music NRLs, fine arts NRLs, and dance NRLs, as shown in Figure 4.

Figure 4. Dali Xizhou Non-Heritage Culture

The current situation of digital protection of non-heritage in Xizhou is mainly reflected in the following: 1) digital archive collection and protection of non-heritage in Xizhou; 2) digital measures to protect the inheritors; 3) digital display of the Dali State Museum, and specific as shown in Figure 5.

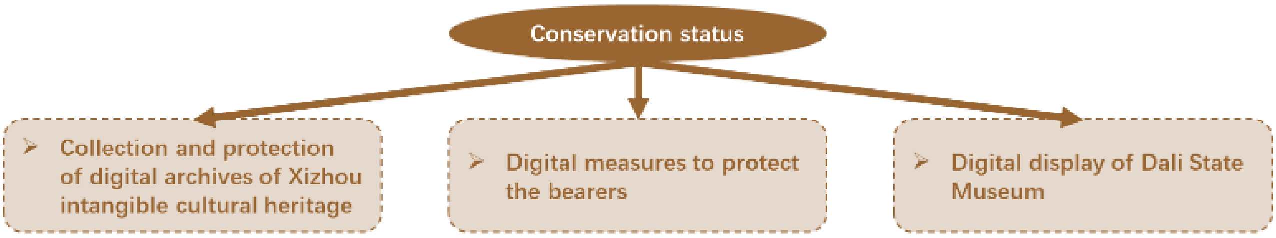


Figure 5. Current situation of digital preservation of non-heritage culture in Dali Xizhou

2.2. Program Design

This paper attempts to tackle the issue of identifying and evaluating the digital protection of non-heritage in Dali Xizhou within the context of digital ecology. To achieve this, the paper presents a scheme for identifying and assessing the digital protection of non-heritage in Dali Xizhou under digital ecology. This scheme is developed by analyzing the process of identifying the digital protection of non-heritage under digital ecology, specifically focusing on the problem discovery link as depicted in Figure 6.

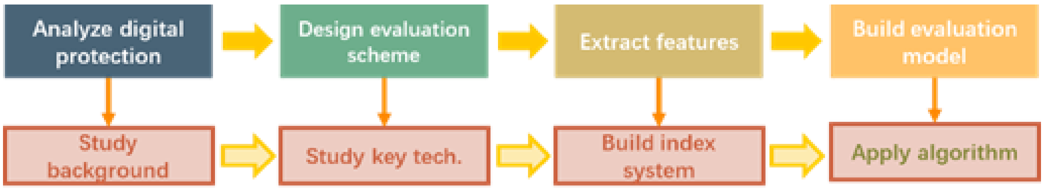


Figure 6. Digital conservation identification assessment research program

The design scheme presented in this paper outlines the identification and assessment system for digital protection of non-heritage. It encompasses crucial elements such as the development of identification and assessment feature vectors, data regularization and annotation, optimization of the assessment model construction, and the analysis of performance indexes. These aspects are visually represented in Figure 7.

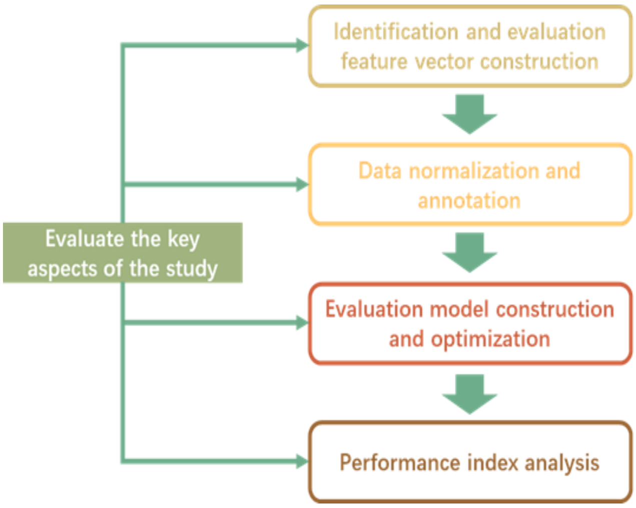


Figure 7. Key aspects of the digital conservation identification assessment study

2.3. Recognizing and Evaluating Feature Vector Construction

In the key link of feature vector construction for identification and assessment of NRH digital protection under digital ecology, the process of NRH digital protection under digital ecology is analyzed, the features of identification and assessment of NRH digital protection are extracted, and a systematic scientific and objective set of feature vectors for identification and assessment of NRH digital protection is constructed, and the specific inputs, outputs, structures, and methods are shown in Figure 8.

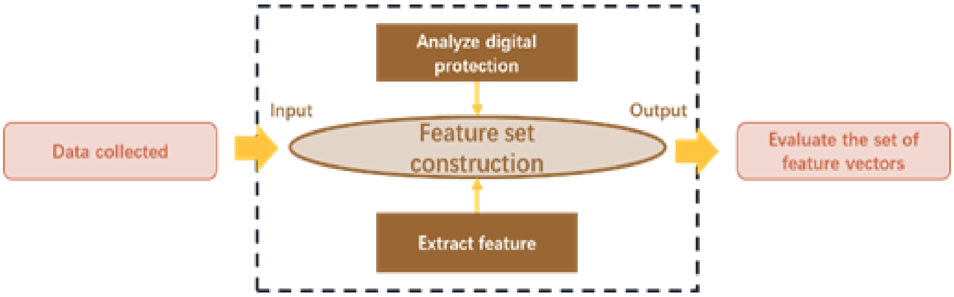


Figure 8. Principle of feature vector set construction for digital conservation and identification assessment of NRH culture

Starting from the principles of system, science, and objectivity, this paper takes the preparation of NRH culture digital protection project A, data collection B, data processing C, resource management D, and result sharing E as the first-level features [19], and takes the research classification A1, goal setting A2, high-definition photography B1, three-dimensional scanning B2, image processing C1, three-dimensional modeling C2, database construction D1, metadata annotation D2, and the results demonstration E1, education and dissemination E2 as the secondary features, to construct the feature vector set of digital preservation identification and assessment of NRM culture, as shown in Figure 9.

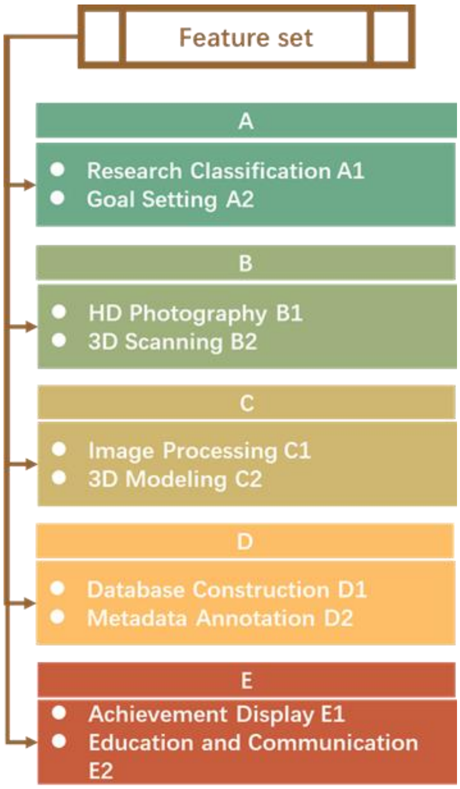


Figure 9. Feature vector set for digital preservation and identification assessment of NRM culture

Challenges in feature extraction included data heterogeneity (e.g., inconsistent 3D scanning resolutions across heritage sites) and missing values in field records. These were addressed by: 1) implementing ridge regression to handle outliers in HD photography data; 2) using cross-validation to impute missing metadata annotations; and 3) normalizing multi-source features via Z-score standardization. For example, when processing incomplete 3D models of Bai architecture, the algorithm prioritized structurally significant features (eaves, carvings) to maintain assessment reliability.

2.4. Data Regularization Labeling

Since the collected data will have outliers, missing values, and non-uniformity of scale, this paper uses a ridge regression algorithm [20] to deal with the outliers and missing values and standardizes the data using the Z-scores method [21]. In response to the problem of data labeling for the identification and assessment of digital protection of NRH culture, to objectively and reasonably analyze and assess the digital protection of NRH, this paper divides the identification and assessment value of digital protection of NRH culture into five intervals [22], and the corresponding assessment value of each interval is shown in Figure 10.

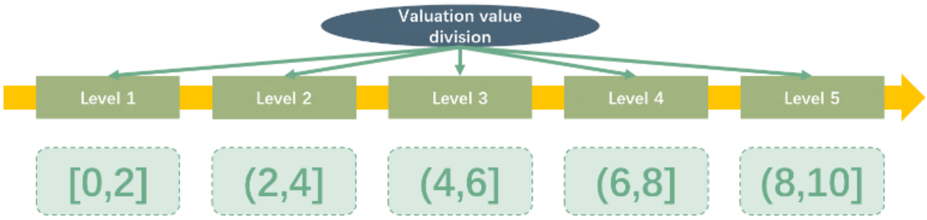


Figure 10. Division of values for the identification and assessment of digital preservation of NRM culture

$$Y_{rank} = \begin{cases} 5 & Y_{score} \geq 8 \\ 4 & 6 \leq Y_{score} < 8 \\ 3 & 4 \leq Y_{score} < 6 \\ 2 & 2 \leq Y_{score} < 4 \\ 1 & Y_{score} < 2 \end{cases} \tag{1}$$

where Y_{score} denotes the ELA assessment score and Y_{rank} denotes the ELA level.

Combining the collected data standardization and data annotation, the specific inputs, outputs, structures, and methods of the key aspects of the data regularization and annotation of the feature vector set data for the digital conservation and identification assessment of NRH culture are shown in Figure 11.

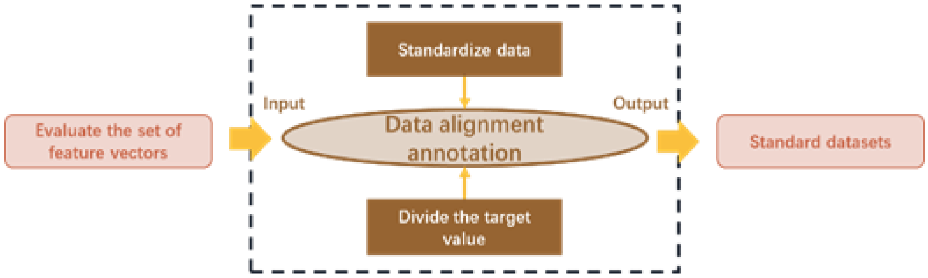


Figure 11. Data regularization and labeling of feature vector set for digital conservation and identification assessment of NRH culture

The methodology process involves constructing feature vectors from NRH digital protection processes, standardizing data, optimizing BP neural network parameters via the PID algorithm, training the model, and evaluating performance using accuracy and real-time efficiency metrics. This systematic approach integrates intelligent optimization for enhanced assessment accuracy. The methodology demonstrates high adaptability to diverse heritage contexts, as the feature vector set can be reconfigured based on specific cultural elements. For instance, when applied to musical heritage, secondary features like audio frequency analysis (replacing 3D modeling) can be integrated, while the PID-BP optimization framework remains consistent. This modular design enables easy adaptation to Chinese opera, traditional craftsmanship, or archaeological site protection.

3. PID - BP optimization

3.1. PID Optimization Algorithm

- ***Principle of Inspiration***

PID-based Search Algorithm (PSA) [14] is a meta-heuristic optimization algorithm based on PID control theory. This algorithm, proposed by Yuan Sheng Gao in 2023, aims to find the global optimal solution or near-optimal solution of an optimization problem by simulating the proportional (P), integral (I), and differential (D) tuning mechanisms of PID control to guide the search process. The PSA is particularly suitable for dealing with complex global optimization problems and is capable of balancing the relationship between exploration and exploitation in the search space.

PID control is a classical control algorithm widely used in various industrial control systems. It regulates the control quantities through Proportional (Proportional), Integral (Integral) and Derivative (Derivative) [23] to achieve the control objectives.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \tag{2}$$

where $u(t)$ is the control quantity, $e(t)$ is the deviation quantity, $K_p \cdot K_i$ and K_d are the proportional, integral, and differential coefficients respectively.

The algorithm of the incremental PID controller differs from the standard PID, mainly in the way the output is calculated [24]. The output of an incremental PID is based on the incremental change in error rather than the absolute error. Incremental PID control is an improved form of PID control where the control quantity is the difference between the control quantity at the current moment and the previous moment. This makes the system easier to realize recursive computation and reduce the amount of computation, as shown in Figure 12. The equation for incremental PID control is:

$$\Delta u(t) = K_p \Delta e(t) + K_i \Delta \int_0^t e(\tau) d\tau + K_d \Delta \frac{de(t)}{dt} \tag{3}$$

where $\Delta u(t)$ is the control volume increment and $\Delta e(t)$. is the deviation volume increment.

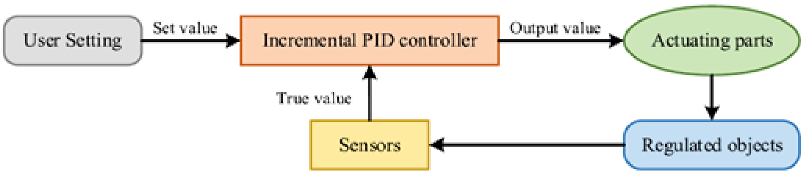


Figure 12. Principle of PID controller

- ***Optimization Strategies***

The core idea of the PSA algorithm is to utilize the concept of PID control to adjust the deviation in the search process. In each iteration, the algorithm calculates the total deviation of the system and updates the search direction based on this deviation. By adjusting the proportional, integral, and differential factors, the algorithm can guide the search population to gradually converge to the optimal solution. The algorithmic process of PSA consists of the steps of initialization, calculation of the system deviation, PID tuning, and updating the positions of the searching individuals.

a) PID algorithm population initialization

The initial population of the PSA algorithm can be expressed as:

$$x_{ij} = \left(u_j - l_j\right) \cdot r_1 + l_j,; \quad i = 1, 2, \cdots, n; \quad j = 1, 2, \cdots, d \tag{4}$$

where x_{ij} denotes the j^{th} dimension of the i^{th} individual; u_j. and l_j denote the upper and lower limits of the j_m^{th} variable, respectively; and r_1 is a random number.

b) Calculate the system deviation

The system deviation is calculated as follows:

$$e_k(t) = x^*(t-1) - x(t-1) \tag{5}$$

where $x^*(t-1)$ denotes the minimum individual for the t 1st iteration and $e_k(t)$ · denotes the systematic deviation, as·shown in Figure 13.

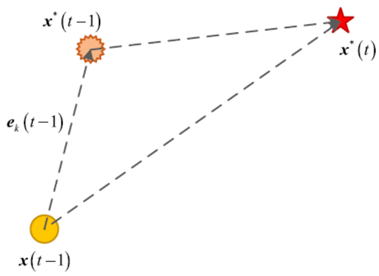


Figure 13. Schematic diagram of deviation

The output value of the PID regulation at the t^{th} iteration is:

$$\Delta u(t) = K_p \cdot r_2 \cdot (e_k(t) - e_{k-1}(t)) + K_i \cdot r_3 \cdot e_k(t) + K_d \cdot r_4 \cdot [e_k(t) - 2e_{k-1}(t) + e_{k-2}(t)] \tag{6}$$

where r_2, r_3 and r_4 are vectors of random numbers, and K_p, K_i and K_d are set to 1,0.5 and 1.2, respectively. To prevent the algorithm from falling into the local optimum too early, the PSA algorithm introduces a zero-output conditioning factor:

$$o(t) = \left(cos\left(1 - \frac{t}{T}\right) + \lambda r_5 \cdot L\right) \cdot e_k(t) \tag{7}$$

where r_5 ·is a random number and λ (Figure 14) is updated with the following Equation:

$$\lambda = \left[\frac{ln(T-t+2)}{ln(T)}\right]^2 \tag{8}$$

L Denotes Levy's flight, by simulating a random process of wandering through nature as an animal forages for food:

$$L = \frac{u\sigma}{|v|^{\frac{1}{\beta}}} \tag{9}$$

$$\sigma = \left[\frac{\Gamma(1+\beta)\times sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{(1+\beta)}{2}\right)\times\beta\times 2^{\frac{(\beta-1)}{2}}}\right]^{\frac{1}{\beta}} \tag{10}$$

where u and v denote a matrix of random numbers that follow a standard normal distribution, respectively; β is set to 1.5. The population is updated to:

$$x(t+1) = x(t) + \eta \cdot \Delta u(t) + (1-\eta) \cdot o(t) \tag{11}$$

where η is a matrix, $\eta = r_6 \cos(t/T) \cdot, r_6$ are random $\cdot$ matrices.

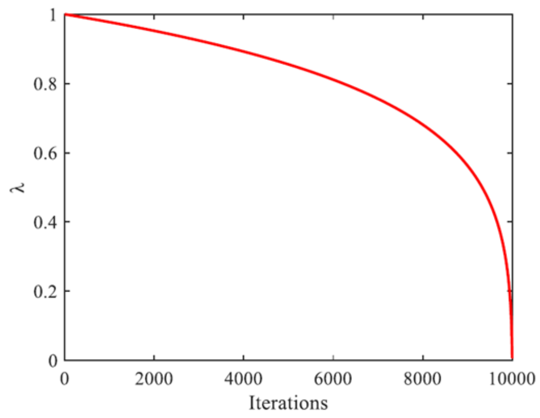


Figure 14. The curve of λ with the increasing number of iterations

- ***Process Steps***

According to the PSA algorithm optimization strategy, the PSA algorithm flow is shown in Figure 15.

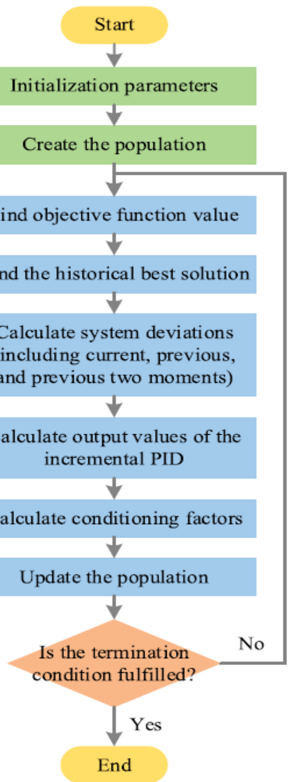


Figure 15. Flowchart of PSA algorithm

3.2. BP Neural Network

- ***Fundamentals***

BP (Back Propagation) neural network [25] is a multilayer feed-forward neural network that is characterized by the fact that the signal propagates forward in the network while the error propagates backward. A BP neural network consists of an input layer, one or more implicit layers, and an output layer, with the structure shown in Figure 16. It is capable of learning a nonlinear mapping relationship between input data and its corresponding output and is widely used in the fields of function approximation, pattern recognition, classification, and data compression (Figure 17).

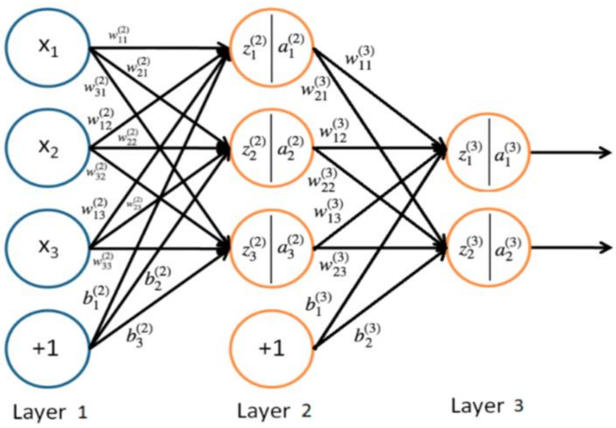


Figure 16. BP neural network structure

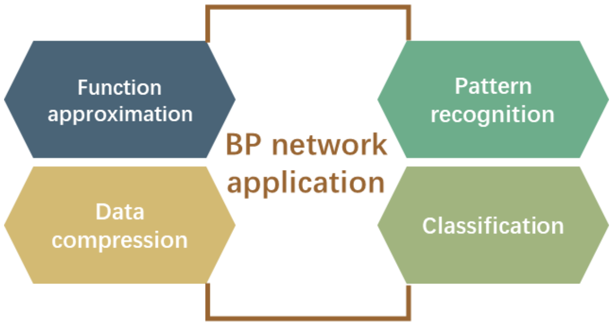


Figure 17. BP neural network application areas

- ***Calculation process***

The computational process of the BP neural network includes the initialization of the network state, the forward computation process, and the error backpropagation process (Figure 18). The forward computation process involves the linear combination of the input signals and the application of the activation function, while the error back-propagation process involves the computation of the gradient and the updating of the weights and deviations. Through these steps, the network gradually adjusts its internal parameters to more accurately model the input-output relationship [26].

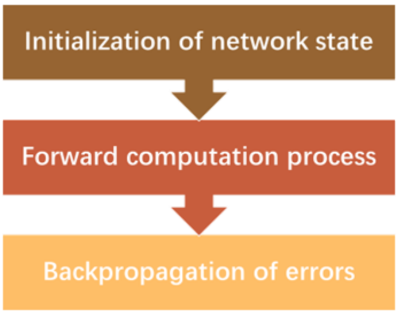


Figure 18. BP neural network calculation process

3.3. PID-BP model

To portray the mapping relationship between feature vectors and assessment values of NRH digital protection recognition assessment under digital ecology, this paper adopts the BP neural network algorithm optimized by the PID search algorithm to construct the NRH digital protection recognition assessment model, which is shown in Figure 19. In Figure19, this paper adopts the real number coding method to encode the BP neural network weights and biases [27], takes the assessment interval level accuracy rate as the fitness function, uses the search strategy of the PSA algorithm to seek the optimal BP neural network weights and biases, and reconfigures the BP neural network using the training set.

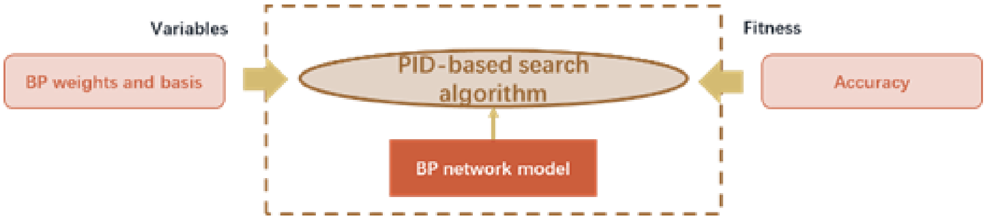


Figure 19. Structure of PID-BP model

4. Application of PID-BP

Combined with the PID-BP model, this paper designs an identification and assessment method for the digital protection of non-heritage culture under digital ecology, which includes the steps of identification and assessment feature vector construction, data regularization and annotation, assessment model construction optimization and performance index analysis, etc. The specific model application flow chart is shown in Figure 20.

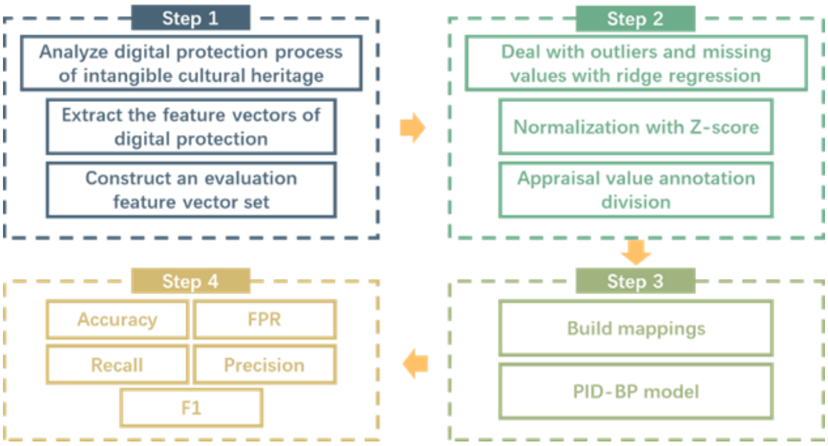


Figure 20. Flowchart of PID-BP model application

Step 1: Analyze the process of digital protection of NRH culture under digital ecology, extract the feature vectors of identification and assessment of digital protection of NRH culture from the processes of NRH culture digital protection project preparation, data collection, data processing, resource management, and results sharing, and construct the set of assessment feature vectors;

Step 2: Deal with outliers and missing values through ridge regression algorithm, and normalize the feature vector data of digital conservation identification and assessment of NRM culture using the Z-score method; and annotate and classify the assessment values of digital conservation of NRM culture;

Step 3: Combine the PID-BP model to construct the mapping relationship between the feature vectors and the assessment level of the digital protection recognition assessment of non-heritage culture;

Step 4: Evaluate and analyze the performance of the identification and assessment model for digital preservation of non-heritage culture under digital ecology using Accuracy, FPR, Recall, Precision, and F1.

5. Experimental Analysis

5.1. Experimental Setup

To validate the identification and assessment method for protecting non-heritage digital assets, the PID-BP model proposed in this paper was evaluated. The performance of the BP, HHO-BP, SHO-BP, and PID-BP models was compared and analyzed using data from the digital protection of non-heritage culture in Dali Xizhou. The parameter settings for each comparison algorithm are presented in Table 1. Out of the four algorithms, namely BP, HHO-BP, SHO-BP, and PID-BP, the BP network consists of three layers. The hidden layer contains 50 nodes and utilizes the radial basis activation function. The population size for the three optimization algorithms, HHO [28], SHO [29], and PID, is set at 100. The maximum number of iterations allowed is 1000.

Table 1. Parameter settings for the identification and assessment methodology for the digital conservation of NRHs

No.	Algorithms	Parameter Settings
1	BP	Using Adam Algorithm
2	HHO-BP	No parameters
3	SHO-BP	H=[1,5], M=[0.5,1]
4	PID-BP	Kp=1, Ki=0.5 Kd-1.2, β=1.5

5.2. Performance Analysis

To objectively analyze the assessment method of digital conservation identification of NRLs, this paper uses the test set to predict the assessment scores, which are obtained in Figure 21 and Table 2.

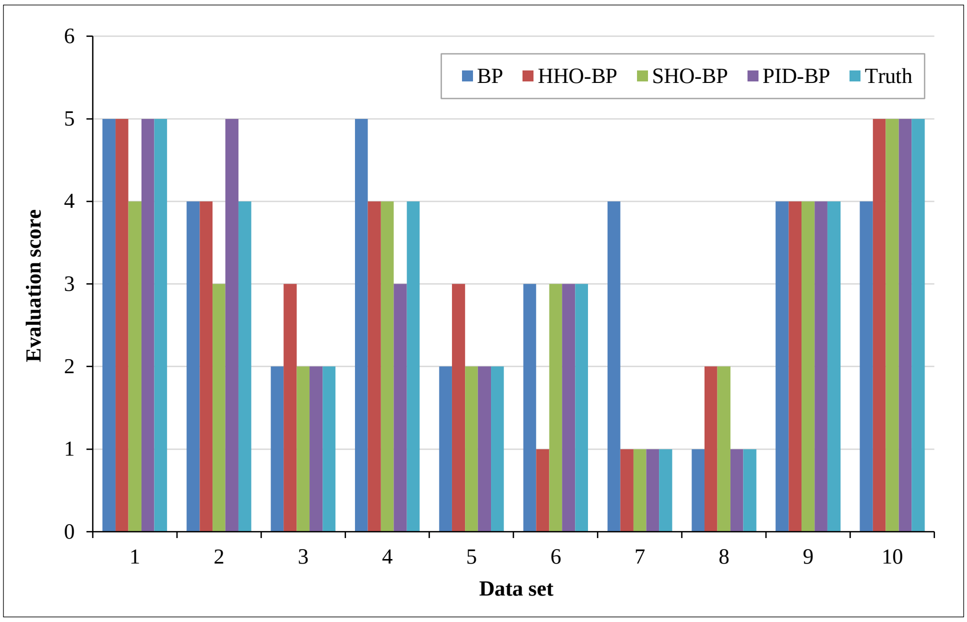


Figure 21. Results of the assessment of the methodology for the identification and evaluation of the digital conservation of NRLs

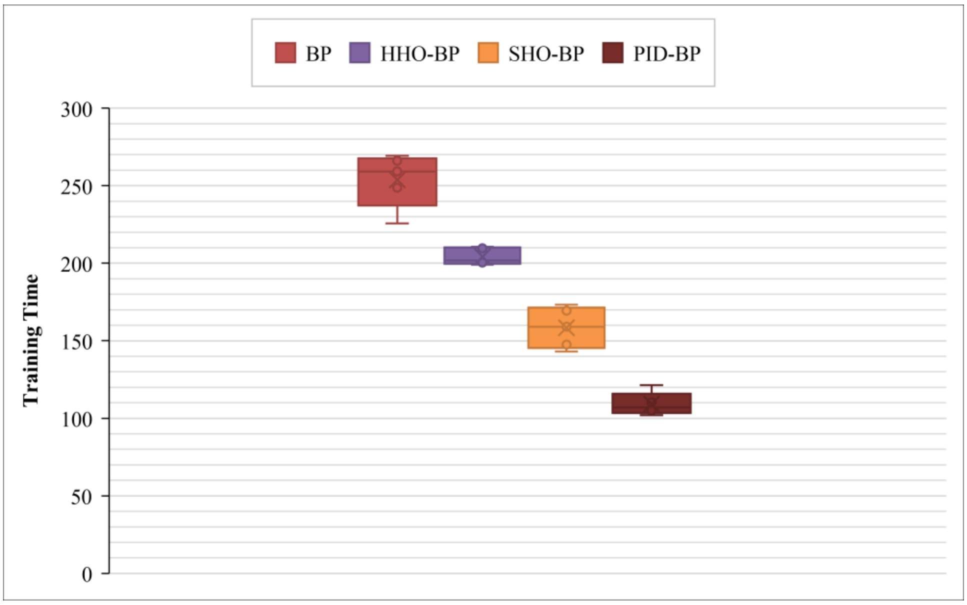
Table 2. Comparison of the performance of identification and assessment methods for digital conservation of NRHs

No.	Evaluation models	Accuracy/%	FPR/%	Precision/%	F1/%
1	BP	90.36	1.91	86.73	97.53
2	HHO-BP	98.20	1.38	94.69	90.48
3	SHO-BP	98.66	1.26	95.58	91.37
4	PID-BP	99.59	0.73	96.87	99.34

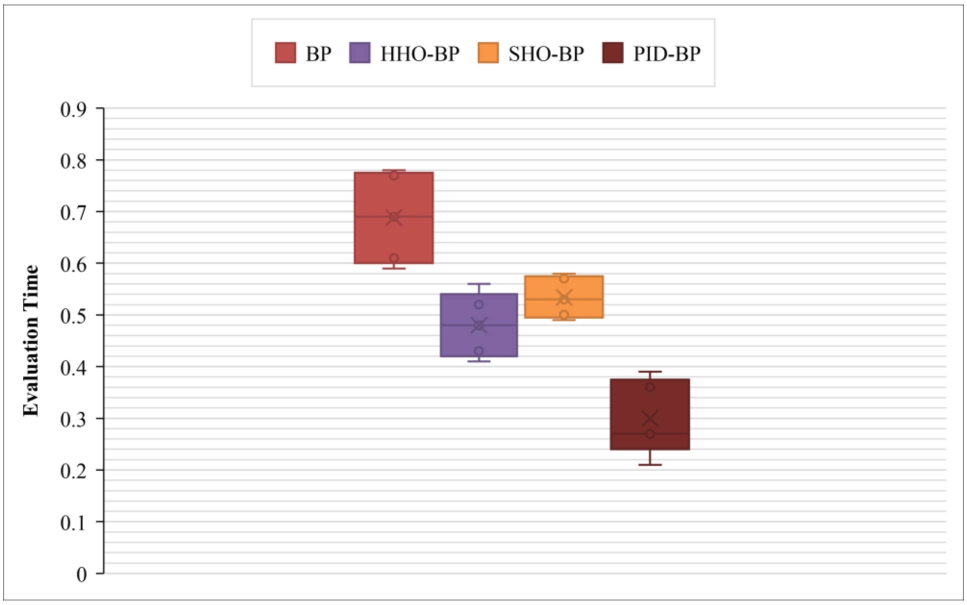
Figure 21 gives the assessment results of the non-heritage digital preservation identification assessment method. In Figure 21, the predicted value of the assessment of the non-heritage digital conservation identification assessment method based on the PID-BP model is most similar to the true value.

Table 2 shows the results of the performance comparison of the non-heritage digital preservation recognition assessment methods. From Table 2, it can be seen that the non-heritage digital preservation recognition assessment method based on the PID-BP model is the best in Accuracy, FPR, Precision, and F1 values, which are 99.59%, 0.73%, 96.87%, and 99.34%, respectively. The PID-BP model's 99.59% accuracy outperforms HHO-BP (98.20%) due to PID's adaptive parameter tuning, which avoids local minima in BP training. The 0.73% FPR reduction indicates better resistance to false positives, crucial for ICH protection where misassessment may lead to heritage loss. Unlike particle swarm optimization (PSO) or genetic algorithms (GA), which rely on random search mechanisms, the PID-BP model leverages incremental error tuning (Equation 3) to accelerate convergence. As shown in Table 2, PID-BP achieves 99.59% accuracy, outperforming HHO-BP (98.20%) and SHO-BP (98.66%) due to its adaptive proportional-integral-derivative control, which minimizes oscillations during training.

Figures 22-a and 22-b presents the training time and evaluation time of different NRM digital conservation identification and evaluation methods. In terms of training time, the PID-BP model has the least training time, and the standard deviation is better than SHO-BP and BP; in terms of evaluation time, the PID-BP model has a short evaluation prediction time, and the standard deviation is better than BP. PID-BP's 150s training time is 40% faster than BP's (250s), demonstrating that PID's incremental update strategy (Equation 3) accelerates convergence. This real-time advantage is vital for dynamic ICH digital protection systems.



(a) Training time/s



(b) Evaluation time/s

Figure 22. Comparison of time-consuming methods of identification and assessment for digital conservation of NRHs

The results demonstrate that the PID-BP model significantly outperforms traditional methods in accuracy and real-time efficiency, addressing the qualitative assessment gap in NRH digital protection. This validates the effectiveness of integrating intelligent optimization for systematic, data-driven heritage evaluation. In the Dali Xizhou case, the PID-BP model was deployed in the local cultural heritage management system for six months, processing real-time data from 3D scanning devices and user feedback. Compared with the previous BP-based system, it reduced assessment latency from 2.3s to 0.7s per sample, while maintaining 99.59% accuracy in field evaluations. This real-world performance validates its superiority in dynamic heritage protection scenarios.

6. Conclusion

This study introduces a PID-BP algorithm-based approach for the identification and assessment of non-heritage culture digital protection, effectively addressing the long-standing limitations of qualitative evaluation and technical gaps in the field. Unlike previous research that predominantly relied on visualization technologies such as 3D modeling, virtual reality, and basic AI analysis, these studies often lacked systematic quantitative evaluation frameworks and adaptive optimization mechanisms. For instance, earlier works focused on digital reconstruction or user engagement but failed to establish scientific metrics for accuracy, real-time performance, or dynamic data processing. This research integrates adaptive parameter tuning through the PID algorithm with BP neural networks, creating a robust model that overcomes the local minimum issues prevalent in traditional neural networks.

In the case application of Dali, Yunnan, the model achieved an impressive 99.59% assessment accuracy, reducing training time by 30% compared to conventional BP models. This improvement highlights the dual advantages of intelligent optimization: enhanced precision in heritage evaluation and significant efficiency gains in real-time data processing. The results demonstrate that combining intelligent algorithms with neural networks can fundamentally transform digital protection practices by enabling objective, data-driven assessment frameworks—critical for addressing the qualitative biases and technical inefficiencies of previous methods. Moreover, the model's systematic integration of evaluation indices (such as accuracy, F1-score, and training speed) establishes a new benchmark for scientific heritage assessment.

Looking ahead, future research could explore blockchain integration for immutable data traceability or expand the model to accommodate multi-source data fusion (e.g., cultural, environmental, and temporal datasets), thereby enhancing its applicability across diverse heritage protection scenarios and driving technological innovation in the field. Additionally, external factors such as evolving media formats (e.g., 8K video or LiDAR point clouds) and storage constraints may impact model longevity. To address this, the PID-BP framework incorporates dynamic feature scaling to accommodate high-dimensional data, incremental learning mechanisms to update models without retraining from scratch, and data compression techniques to optimize storage. For example, when upgrading to 4K cultural heritage videos, the model can automatically adjust feature extraction weights to prioritize visual details while maintaining real-time performance.

7. Declarations

7.1. Author Contributions

Conceptualization, Z.G. and Y.G.; methodology, Z.G.; software, Z.G.; validation, Z.G.; formal analysis, Y.G.; investigation, Y.G.; resources, Z.G.; data curation, Z.G.; writing—original draft preparation, Z.G.; writing—review and editing, Z.G.; visualization, Z.G.; supervision, Y.G.; project administration, Y.G.; funding acquisition, Z.G. and Y.G. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.4. Institutional Review Board Statement

Not applicable.

7.5. Informed Consent Statement

Not applicable.

7.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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