Application of Video Game Algorithm Based on Deep Q-Network Learning in Music Rhythm Teaching

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Abstract: *The difficulty of music rhythm teaching makes its teaching effect limited. Some game algorithms show problems of stuttery and unclear picture when they are introduced into teaching, which greatly restricts the development of teaching content. Therefore, it is proposed to activate the Deep Q-Network (DQN) and improve the filter to improve the processing performance of game image data and the integrity of information retention. The model fuses the extracted features and processes them through the neural network. According to the performance characteristics and forms of music rhythm, constant Q-transformation, dynamic programming algorithm and hidden Markov model are proposed to analyze and design music signal, beat point analysis and signal traveling speed, so as to realize the identification and matching of music rhythm. The performance test and application analysis of the proposed fusion improvement algorithm are carried out: the video game algorithm can effectively extract data feature information, and its accuracy rate is basically 90% or above. The improved DQN and Artificial Fish Swarms Algorithm (AFSA) algorithms can maintain an accuracy of over 75%, followed by the ABC algorithm, which maintains an accuracy of over 70%, but exhibits significant fluctuations in the curve changes and nodes. The recognition accuracy of music signal feature extraction is over 70%, and it is less affected by signal-to-noise ratio. The improved activation function showed that the highest game score exceeded 10 points, while the scores of Rectified Linear Unit (ReLU) function and Hyperbolic tangent function (Tanh) function were basically hovering below 5 points, and the overall score curve fluctuated significantly. The recognition accuracy of music signal features extraction is above 70% and is less affected by signal to noise ratio. The algorithm has a good effect of music rhythm teaching, the students' interest in classroom learning is more than 45%, and the learning weakness is less. The average score of students in music style judgment, rhythm division and index are 85 points and 90 points respectively, which is much higher than the 40 points and 63 points of traditional teaching. The proposed algorithm can better combine video games with music teaching and help students improve their learning effect under the gamification teaching method, and has good application value.*

Keywords: *DQN network learning, video game algorithms, the rhythm of music, teaching practice.*

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1. Introduction

The application of video games in the design of teaching schemes can effectively combine the interaction and vividness of games with the knowledge of teaching, thus breaking the limitations brought by traditional teaching methods. The continuous expansion of artificial intelligence makes deep learning algorithms gradually become an important solution to problems. To better conduct teaching research on video game algorithms, this study proposes to combine reinforcement learning with neural network to give full play to its advantages in solving sequential decision problems and the ability to extract data features. Among them, Deep Q-network (DQN), as a reinforcement learning algorithm based on neural networks, can realize automatic learning of optimal strategies, thus ensuring the intelligence of decision-making [29]. The DQN algorithm uses the function approximator of Q-learning to predict the output of the input state and match the expected score of the action. The DQN predicts the Q value of each action based on information about the state of the environment and past experience. This algorithm enables the agent to find the optimal decision method in an environment through continuous trial and feedback [10]. The design of music rhythm teaching with the help of this algorithm can help students create an environment for music game learning in a virtual environment, thus improving students' grasp and initiative of music rhythm [15]. However, overestimation of Q value is inevitable in DQN algorithm, so this paper proposes an improved deep reinforcement learning DQN algorithm to improve it. In this study, the improved DQN is applied to video game music teaching to improve the effect and quality of music rhythm teaching. The research mainly analyzes the problem of music rhythm teaching from four aspects. The first part is about the current video game algorithm in music rhythm teaching methods to review and discuss the relevant literature. The second part proposes the improved video game algorithm and the design of music rhythm teaching method respectively. The third part is to test and analyze the effect of rhythm teaching under the fusion method. The last part is the summary of the full text.

2. Related Work

The teaching form of gamification can better make learners feel the fun of learning in the interaction. Video game algorithm can confirm the positive feedback of learning through rhythm game training in music rhythm teaching design. Among them, there are a lot of algorithm research and scene application analysis for game design. Scholars such as Khan *et al*. [14]. proposed a game scene testing algorithm based on DQN and deep recursive Q-network. The algorithm predicts algorithm performance differences by building a test bed. The video game algorithm built can predict the location of characters with an accuracy of more than 70%. To solve the problem that game patches limit the normal operation of the training model, Smerdov *et al*. [24]. scholars use sensor data analysis to conduct predictive analysis of the game and train the machine learning model. The algorithm model has a prediction accuracy of 88.3%. To find the model parameters more suitable for the rolling time domain evolutionary algorithm, Gaina *et al*. [7]. and other scholars optimized a large number of existing models and combined them with the parameter optimizer of the N-tuple evolutionary algorithm to find the best combination parameters of the models and form a large-scale game hybrid algorithm. It is feasible to find the optimal configuration of parameters in large-scale hybrid algorithms. DQN algorithm has been used in many fields. Wang *et al*. [26] designed an intelligent voltage control method based on average weighted double DQN algorithm, inspired by the voltage control of DQN algorithm. In this method, the voltage control objective is included in the incentive mechanism, and the Markov decision model is further formed after normalization. Simulation experiments based on this algorithm show that the algorithm has better convergence. To solve the problem of poor hyperparameter generalization ability of meta-heuristic algorithm, Zeng *et al*. [31] proposed a dynamic hyperparameter adjustment framework based on DQN, and introduced genetic algorithm for training. Compared with other algorithms, the training effect based on DQN algorithm is better. DQN algorithms are also used to build network systems. Chen *et al*. [3] assigned weights to network subtasks according to the chromatography analysis method, and combined the DQN algorithm to simplify the task flow. The combination of the two can better reduce the system cost.

Rhythm is the life of music, but in today's music rhythm teaching, many students think that rhythm is just a numerical, mathematical mechanical reaction, can't feel and reflect the beauty of music. So, scholars have explored more teaching methods that can stimulate students' interest. Scholars such as Yi [28] incorporated traditional Korean music into western music curriculum and provided guidance for music teaching in primary and secondary schools by combining music history and rhythm. Through questionnaire experiments, Borges and Richit [22] found that teaching related to music theory knowledge and practice was mostly integrated with digital technology, while teaching related to music rhythm and melody was usually connected with other fields. Therefore, an emerging learning algorithm is adopted for interaction. In the teaching of music rhythm, scholars such as Fuchs *et al*. [6] used online visual tools to enable teachers and students to achieve visual and interactive effects. Meanwhile, clustering steps are explored and parameters are improved to optimize the teaching model, providing opportunities for future development. To innovate music score reading skills, James and Reifinger [11] summarized the teaching skills of teachers in a large number of orchestras. A large number of teaching methods focus on reading and singing pitch notation, which have strong applicability in different teaching stages. Grekow [9] applied recurrent neural network algorithm to music emotion detection and proposed a framework for audio feature extraction of learning networks based on long short-term memory units. In this study, a software package was used to make the framework concrete. The algorithm has strong emotion recognition ability and can be used in daily training and teaching. Muller *et al*. [19] and other scholars applied Fourier transform to the field of music to explore the application of music to signal processing. This method makes an in-depth analysis of classical signal processing methods and provides a good reference for music education.

To sum up, in video game design, some scholars use DQN and its related improved algorithms for data processing and information extraction. Such as the combination of DQN and deep recursive Q-network, in the game scene design. In addition, the design of parameter optimizer and the introduction of sensor data prediction model are also mentioned. Based on the effectiveness of machine algorithms in game design, this study proposes an improved video game algorithm for DQN networks. According to the characteristics of music rhythm teaching, dynamic programming and hidden Markov model are introduced to extract music rhythm characteristics, so as to better design and meet the needs of music teaching.

3. Research on the Application of Video Game Algorithm Design to Improve DQN Network Learning in Music Rhythm Teaching

With the emergence of computer technology and human-computer interaction means, the development of video games has entered a new stage of development. It has gradually changed from the original rough picture and single game difficulty to a vivid game virtual environment and interactive game experience, which greatly improves the applicability of video games, and makes its application field gradually expanded. In this study, the activation function and filter of the classical DQN algorithm are improved, and the video game design under the improved DQN algorithm is carried out. In addition, according to the characteristics and difficulties of music rhythm teaching, this study designed music rhythm feature algorithm to better realize the effectiveness and applicability of the improved algorithm in music rhythm teaching design.

3.1. Improved Video Game Algorithm Design for DQN Network Learning

The deep Q-learning algorithm proposed in this paper combines the advantages of convolutional neural network and reinforcement learning. Q-learning algorithm mainly uses tables to store queue information of small space dimension information. For large spatial state dimensions, deep neural networks are used for function approximation design to optimize network parameters [12]. The loss function can be expressed as Equation (1) [33].

$$L(\theta_i)=E_{s,a,r,s'}[(r+\gamma\max_{a'}Q(s',a'|\theta_i^-)-Q(s,a|\theta_i))^2] \quad (1)$$

In Equation (1), *s*, *a*, *r*, *s*' represents queue information; Where *s*, *s*' represents choice; *a* is the status; γ is a discount factor; *r* is an award; *E* represents maximum cumulative return; $Q(s, a|\theta_i)$ is an action value function; θ represents neural network parameters. There is a great correlation between states in reinforcement learning, so it is necessary to introduce replay mechanism in the process of network training. The loss function of DQN algorithm can be expressed as Equation (2).

$$L=(r+\gamma\max Q(s',a'|\theta_i')-Q(s,a,\theta)^2 \quad (2)$$

Because reinforcement learning pays attention to the correlation between states, it is easy to cause certain volatility to network training. Common loss function optimization methods include experiential playback mechanism, target network and gradient clipping. The training process of DQN algorithm is shown in Figure1.

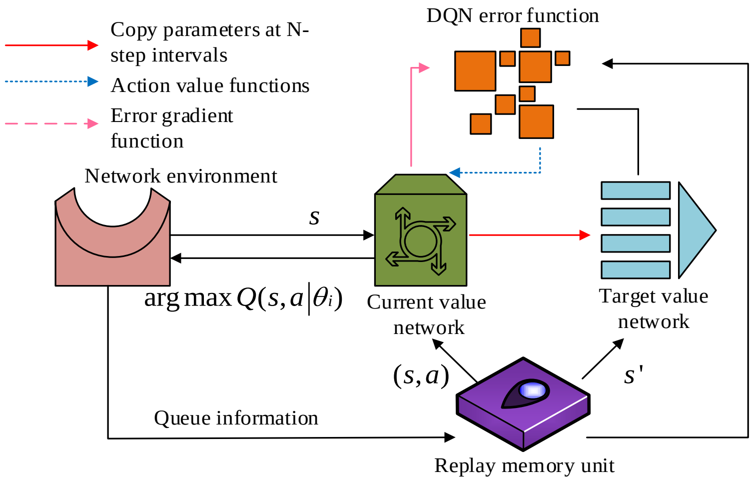


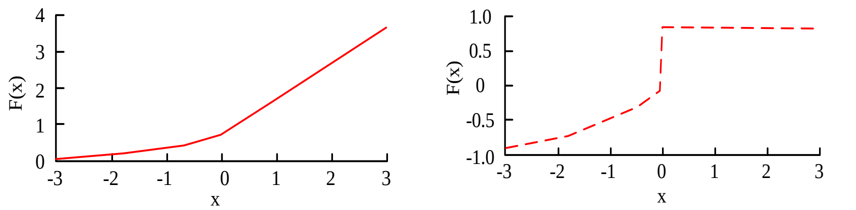
Figure 1. Flowchart of DQN algorithm.

In Figure 1, the DQN algorithm improves the stability of the algorithm by means of empirical replay mechanism, replay memory unit storage and network parameter updating during the training process. In addition, two Connectionless Node Neork Service (CNNS) are used in the structure to achieve the approximation of the action value function and the calculation of the target Q value respectively, and then the mean square error of the calculation of Q value is reduced to some extent. Meanwhile, the range limit of Q value and gradient value of DQN algorithm makes it able to carry out algorithm operation in a reasonable range.

Common network functions include Sigmoid functions, Tanh functions, and Rectified Linear Unit (ReLU) functions. Among them, ReLU function has a relatively good advantage because of its good sparsity and convergence, and its excessive sparsity will not cause partial information loss. Therefore, ReLU function is optimized to make it unsaturated and linearly modified, and its mathematical expression is shown in Equation (3) [20].

$$f(x)=\begin{cases}\ln(1+e^x) & x<0\\ x+\ln 2 & x\geq 0\end{cases} \quad (3)$$

In Equation (3), *x* represents the input value; *e* indicates the base number. Equation (3) shows that when the data is greater than 0 or less than 0, ReLU function and Softplus function can be selected respectively. When different activation functions are selected by judging different input values, the improved activation functions and their derivations can be explained with the help of Figure 2.



a) Improve the activation function image. b) Improving the derivative image of activation function.

Figure 2. Improved activation function image and its guide image.

The value of the improved activation function will show an increasing trend with the change of the input value. The application of improved activation function can better cope with the change of data type. Meanwhile, considering the problem of excessive network layers, the replacement of a single implementation function will lead to large errors in information screening and processing [4]. Therefore, only the application of the improved function in the fully connected layer of DQN network structure is studied. The improved algorithm model is shown in Figure 3.

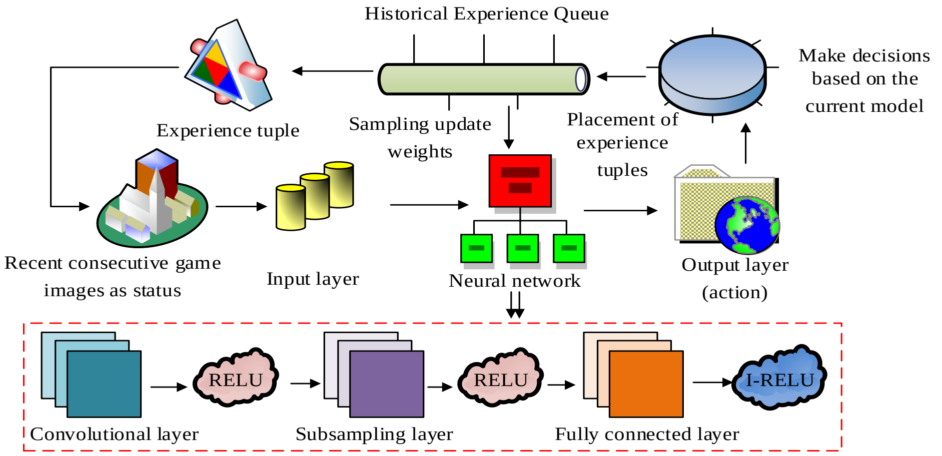


Figure 3. DQN algorithm under improved activation function.

In Figure 3, continuous frame images and trainable filters are used as convolutional inputs; The feature map is obtained by ReLU activation function. Then the mean sampling process is carried out on the obtained feature map, and the mapped sub-sampling layer is obtained. Repeat the above to get the final processed feature map. The historical experience queue can shuffle the serialized data generated by the interaction between the agent and the environment through random sampling, making the data during model training independent and identically distributed, thereby improving the stability and convergence speed of training. And the storage of interactive data in the historical experience queue can reduce dependence on new data, improve generalization ability, and reduce data fluctuations during the training process. The final feature graph is processed by the improved activation function under full connection processing and Q value is obtained. Then the Q value is used to select the optimal scheme and screen the empirical sample queue. The sampling result is used as the initial value of network training, and the difference of Q value is calculated under the error cost function, and the backpropagation algorithm and weight update are used to realize the simulation of video game. Meanwhile, the selection of filters plays an important role in the extraction of image information and the perception of regions.

The mathematical expression of the traditional two-dimensional Gabor filter is shown in Equation (4) [5].

$$G(m,n,\mu,\frac{1}{\sigma},\sigma)=\frac{1}{2\pi\sigma_m\sigma_n}\exp(-0.5(\frac{m'}{\sigma_m^2}+\frac{n'}{\sigma_n^2}))\exp(2\pi m') \quad (4)$$

In Equation (4), σ represents the scale function; m is the horizontal axis; n denotes the vertical axis; σ is the direction of filter feature extraction. The two-dimensional filter is composed of two parts, real and virtual, and the waveforms of the two parts are also very different. Scale difference and direction difference will make the filter show different response effect. To ensure that the filter has better feature extraction ability in both dimension of direction and scale, it is improved. That is, the primary term of the filter is coupled, and the improved primary term of the filter is shown in Equation (5).

$$\begin{cases} m' = m\cos\mu + n\sin\mu \\ n' = -m\sin\mu + n\cos\mu + c(m\cos\mu + n\sin\mu)^2 \end{cases} \quad (5)$$

In Equation (5), c represents the curvature coefficient. Meanwhile, considering the processing of information in the design of game algorithms, strengthening the integration of information can effectively ensure that the content of information is more comprehensive and richer. Principal Component Analysis (PCA) was used to complete the study. PCA can extract data features, transform variables and reduce dimension by linear transformation [13]. To reduce the processing errors of different data, kernel principal component analysis is proposed under PCA algorithm to realize the representation of nonlinear data, which has high differentiation. Equation (6) is the covariance matrix.

$$C = \frac{1}{N}\phi(X)\phi(X)^T \tag{6}$$

In Equation (6), X represents the sample point; X is the point that the sample points are mapped in the high-dimensional feature space through centralized processing; T represents transpose. The DQN network structure after the improved filter is shown in Figure 4.

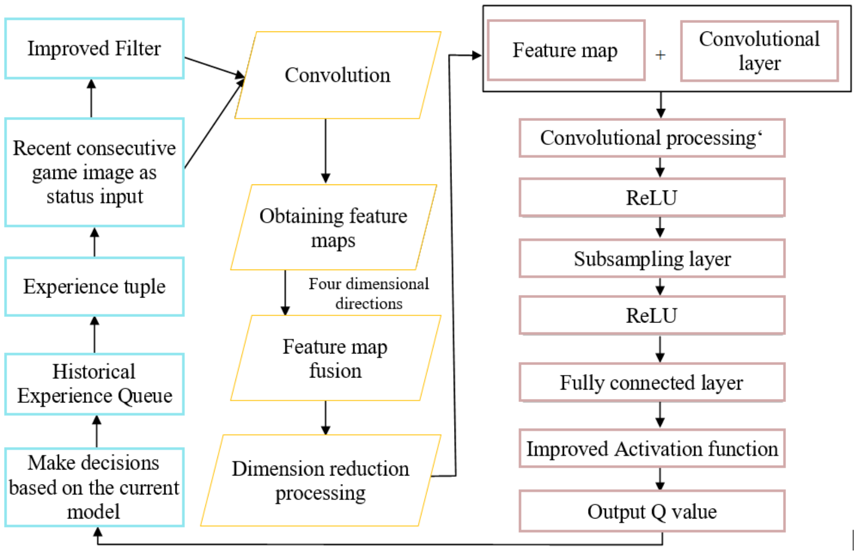


Figure 4. DQN network structure after improved filter.

The improvement idea is roughly the same as the function improvement network structure flow described above, except that the game image needs to be convolved with the improvement filter at the beginning. In addition, it is necessary to extract the feature maps in different Angle dimensions. Then the Angle feature map is fused and dimensionally reduced to get the total feature map. Finally, repeated convolution and function design are carried out on the total feature map, and the final Q value and sample results are screened out. The experience tuple is usually represented as (*s*, *a*, *r*, *s*'), where s represents the current state, a represents the action taken, *r* represents the reward obtained, and *s'* represents the next state to transition to after executing the action. Experience tuples are randomly selected training samples from a historical experience queue, which are used to update the parameters of the Q-network. Through these experience tuples, the model can learn the value of different state action pairs, thereby improving the accuracy of decision-making.

3.2 Music Rhythm Feature Extraction and Identification Design

Video game algorithm refers to the combination of game design and algorithm design to solve problems in computer applications or to complete some specific tasks. The application of video game algorithm of DQN network learning in music rhythm teaching can effectively improve learners' learning effect and interest. The audio signal features of different music rhythms are quite different. Strengthening the recognition and extraction of music signal features can improve the pertinence of game algorithm design. The rhythm of music is an important element to describe the characteristics of the music. The rhythm and the speed of the music can express different aspects of the music, and the expression of the rhythm can be reflected by the repetition of different music beats. This paper studies the use of audio signals to detect beats, and improves the detection method based on source classification [27]. Constant Q Transform (CQT) is a common signal processing transformation method, which transforms data into the frequency domain, and its mathematical expression is shown in Equation (7) [16].

$$\delta_{fk} = 2^{\frac{1}{\tau}} \cdot \delta_{fk-1} \tag{7}$$

In Equation (7), δ_{fk} represents the filter bandwidth; k denotes the number of filters; τ is the number of filters per octave. The frequency resolution of the CQT transform will change with the frequency change, and the positive correlation relationship can make the transformed signal more in line with the hearing characteristics [17]. Meanwhile, to avoid the interference of the directional heterogeneity of different spectrograms on the signal time domain, the harmonic component is separated from the impulse component, and the intermediate frequency filter is used to separate the signal. The spectral energy of the signal can be expressed as Equation (8).

$$W_{W,g} = \left|F_{W,g}\right|^2 \tag{8}$$

In Equation (8), (A^W) represents the frequency point; g represents a point in time; FW, T is the short-time Fourier transform of musical signal. Meanwhile, to ensure the integrity of the rhythm information of the audio segment, the music feature vector is represented, and the intermediate feature is used to detect the beat, that is, the chroma vector. Its mathematical expression is shown in Equation (9).

$$x_{ch}^{k} = \sum_{f_k \in F_k} H_{p,f_k} \tag{9}$$

In Equation (9), p represents the time parameter; H is the harmonic component. Then the graph matrix of each eigenvector is analyzed. Its determination principle is based on the maximum significance of the rhythm value in a certain frame. When the music rhythm value is high, the single constant Q cannot be determined to better know its segmentation, so it needs to use time bending to adjust. Then the corresponding global period can be obtained by iterating the corresponding chrominance feature and filter energy feature of the feature vector. In the case of obtaining the beat period, the beat point tracking is realized based on dynamic programming. This problem is transformed into several problems to solve, and the mathematical expression of correlation significance is shown in Equation (10).

$$s_j^b = r^{\wedge}f_{l,r}(b_j) + r^{\wedge}_{ab,r}(b_j) \tag{10}$$

In Equation (10), $r^{\wedge}f_l$, $_r$, $r^{\wedge}_{ab,r}$ represents the peak value of the feature sequence; bj is the time series of beats. Meanwhile, the distance function is used as the detection function of the beat point, and the weight of the distance function variable is controlled by means of parameters. To ensure the accuracy of rhythm detection when the rhythm changes, it is necessary to take the rhythm value into account in the distance of the beat point. The significance peak of the obtained rhythm value is formed into a curve, and the significance equation of the beat point is updated.

When dynamic programming algorithm is used to analyze the beat point, it is necessary to design the optimal sequence of the target beat sequence which satisfies the minimum objective function. Then the recursive equation is established with the minimum cost of the beat points, and the last beat point is determined by the beat point set at the end of the music, and the best beat sequence is found back. Then the Hidden Markov Model (HMM) is used to estimate the speed of music signal. HMM model is a process of generating several observed values by hidden generating state sequence, which is a sequential probability transfer model [18]. Among them, Zeng M scholar also introduced HMM model to train and model gesture data when using virtual reality to build a piano performance teaching game platform. The results indicate that this method has good application performance [32]. The HMM model can be represented by Equation (11).

$$P(s_t \mid s_1, s_2, s_3, ...s_{t-1}) = P(s_t \mid s_{t-1}) \tag{11}$$

In Equation (11), s_t represents the time random sequence of random variables; t is the moment. The HMM model can be realized by the number of states in the model, the number of observed symbols, the initial state probability, the state transition probability matrix and the state observation matrix. The HMM model has double uncertainties, including Markov chains and random processes, so it can be abbreviated as Figure 5.

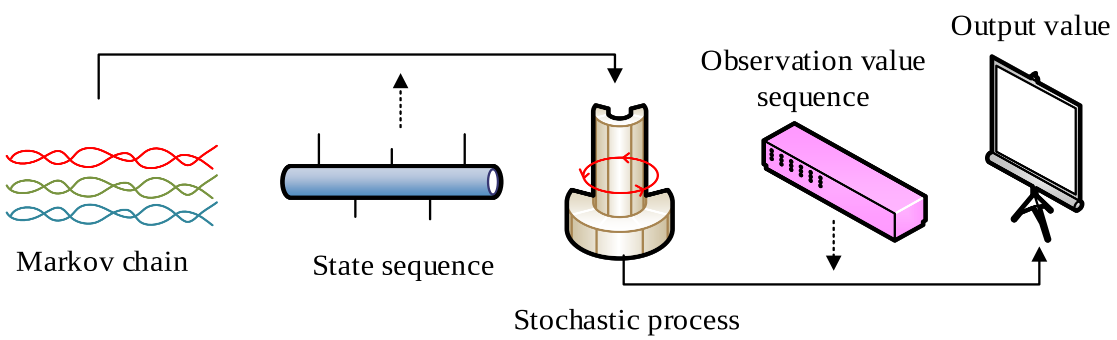
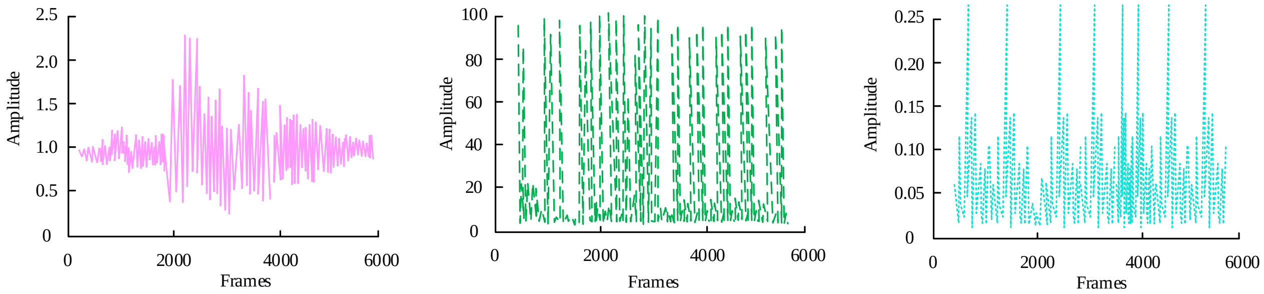


Figure 5. Uncertainty concept diagram of HMM model.

In Figure 5, the probability state of the model and the matrix elements at the initial moment, and the probability value of the model state at a certain moment to the next moment describe the Markov chain. Then the state observation matrix is used to describe the random process, and the output value is used to generate the observation sequence. For different problems of hidden Markov model, the corresponding algorithms are also different. For the evaluation problem, the forward and backward algorithm is needed. The decoding problem of the model needs to be solved by Viterbi algorithm [21]. The identification of music rhythm mainly needs to grasp the speed of music. That is, according to the hearing characteristics of the human ear, the music speed can be divided into fast, medium and slow speed. When selecting music characteristic parameters, the representative parameters, such as short-time average energy and short-time zero crossing rate, are analyzed. Figure 6 shows the short-time average energy diagram of different music speeds.



a) Fast music. b) Medium speed music. c) Slow music.

Figure 6. Short-time average energy diagram of different music speeds.

The energy characteristics of different music signals are quite different. To better identify the characteristic signals, ensure that the information content displayed is more comprehensive and accurate, and avoid the system caused by excessive data volume, it is necessary to carry out parameter dimension reduction processing. When dimensionality reduction of feature parameters is carried out, principal component analysis is used to reduce dimensionality, that is, the principal component eigenvector of corresponding data can be obtained after decomposition by covariance matrix. Then the standardized matrix is constructed to achieve dimensionality reduction, and the mathematical expression of its principal components is shown in Equation (12).

$$u_{ij} = z_i^T b_j^\sigma \tag{12}$$

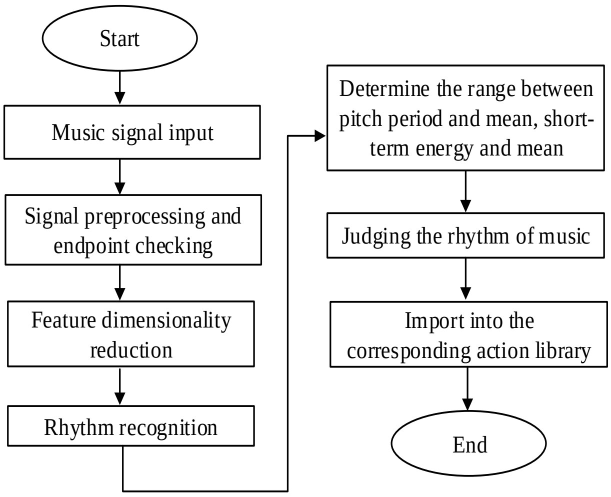


Figure 7. Matching flow chart of movement library and music rhythm style.

In Equation (12), b_j^σ represents the eigenvector of the eigenvalue; T represents a standardized matrix. The weights of different costs represent different contribution rates of variance. This method can reduce the dimensionality of the feature vector after music processing, that is, when the feature vector of music signal is imported into the original data matrix, the matrix is standardized and the related features are extracted. Then the principal component coefficient matrix and dimensionality reduction eigenvector are obtained. Figure 7 shows the flow chart of matching movement library with music rhythm style.

After the music signal is preprocessed, the characteristic signal is extracted and dimensionality is reduced. According to the relationship between pitch period and period, short time energy and mean value, the rhythm is judged to be fast, medium and slow. And the corresponding music rhythm is imported into the movement library, then the music rhythm style can be recognized and matched.

Research selects indicators such as accuracy, recall, and signal-to-noise ratio for evaluation index analysis. Recall rate refers to the proportion of actually positive samples that are correctly predicted as positive samples. It measures the model's ability to identify all positive samples, while accuracy refers to the proportion of correctly predicted samples to the total sample size. In music rhythm teaching, recall rate can be used to measure the algorithm's ability to recognize correct beats, ensuring that all correct beats are accurately detected. Accuracy can reflect the overall performance of the algorithm in all test samples, including a high ability to correctly identify beats and non-beats. Equation (13) is the mathematical expression of recall and accuracy indicators [8].

$$\begin{cases} P = (TP + TN)/(TP + TN + FP + FN) \\ R = TP/(TP + FN) \end{cases} \tag{13}$$

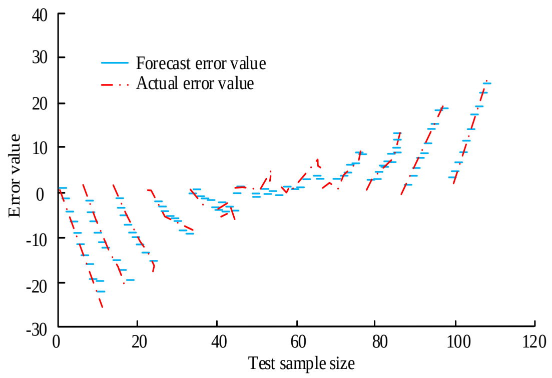
In Equation (13), P represents accuracy, R represents recall, TP represents true examples, TN represents true counterexamples, FP represents false positive examples, and FN represents false counterexamples. Signal to noise ratio refers to the ratio of the power of a signal to the power of noise, which can measure the strength of useful information (signal) relative to background noise. The signal-to-noise ratio represents the algorithm's ability to reduce noise interference while preserving the rhythm features of music. Equation (14) is the mathematical expression of signal-to-noise ratio and accuracy index [2].

$$SNR = 10\log(P/N) \tag{14}$$

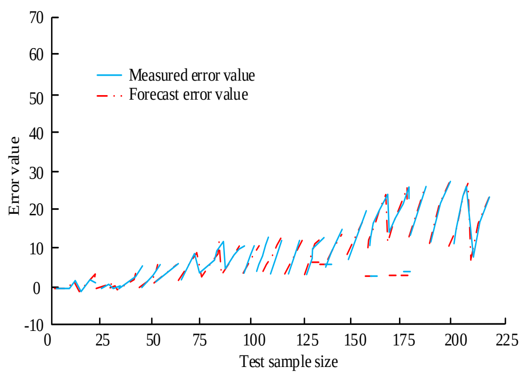
In Equation (14), P represents the peak power of the signal, and N represents the noise power.

4. Improve the Application Effect Analysis of Video Game Algorithm in Music Rhythm Teaching

Using fusion to improve the video game algorithm of DQN network learning can realize the application research in music rhythm teaching. The improved filter extracts and preserves key features from the music signal, reduces noise interference, and ensures information integrity. Afterwards, CQT converts the music signal into a representation in the frequency domain, and HMM performs temporal analysis on the music signal to identify and obtain rhythm features of the music. Extracting and reducing the dimensionality of music feature signals, and determining their rhythm as fast, medium, or slow based on the relationship between the fundamental period and period, short-term energy, and mean. Importing the corresponding music rhythm into the video game action library can achieve interaction and matching between music files and game content, thereby stimulating students' participation in hot situations and improving their learning enthusiasm. This method not only enhances the recognition and matching ability of music rhythm, but also effectively promotes the application and research of music rhythm teaching. Through the interaction in the game process, students are encouraged to participate and their learning enthusiasm is improved. This method can provide students with a more autonomous learning experience, and can also help students better understand the concept of music rhythm and improve the quality of music teaching. In the process of experiment, Python 3.6 language was used for programming design, and Ubuntu 16.04 and TensorFlow version 1.3 were designed. The deep learning algorithm toolkit version is Open AI and gym version is 0.8. The corresponding software environment is designed: CPU is Intel Corei7-7100, memory size is 16G, deep learning framework is TensorFlow, Keras. When conducting accuracy analysis of music features, the selected test dataset is the music theme dataset, which contains multiple files types and covers audio files of different music themes and styles [30]. The audio files include various music styles (such as classical, jazz, pop, rock, etc.,) and music clips played by different instruments. The file format is generally a common audio format and each audio file has one or more annotation files. The annotation files are usually stored in text format (such as Text, Comma Separated Values (CSV), etc.,) and contain rhythm information of the music clips, including beat position, duration, and intensity. This dataset contains multiple music styles and themes, ensuring the ability to test the algorithm's generalization ability on different music genres. All files are standardized to ensure consistent audio quality and provide a unified annotation format for algorithm processing and analysis. All algorithms are analyzed using a unified dataset, which is processed and imported into the game scene. To further test the performance of the video game algorithm proposed in the study, the game environment was designed and the game image input in the experiment parameters was set to 80*80. The effect and performance of the improved DQN algorithm for data extraction are analyzed. Set the learning rate of the network and the maximum number of iteration steps to 0.001 and 800, respectively. The size of the input image directly affects the computational complexity and training time of the model. The 80×80 image size is a compromise between preserving sufficient information and reducing computational complexity. This image size can effectively preserve important features in the game environment, such as the position and motion direction of objects, while not losing key details due to its small size. Moreover, this image size has also been commonly used in previous research. 0.001, as a moderately low learning rate, usually provides a stable learning process, ensuring that the model has a sufficiently fast convergence speed while avoiding instability in the training process caused by a high learning rate. This value is commonly used as the default learning rate in deep learning. The maximum number of iteration steps of 800 can provide sufficient training time for the model to effectively learn and optimize strategies, while also considering experimental efficiency. The selection of these parameters was set as default parameters during the experimental process, based on a comprehensive consideration of past experience and experimental results. The result is shown in Figure 8.



a) Data error situation before DQN network improvement.

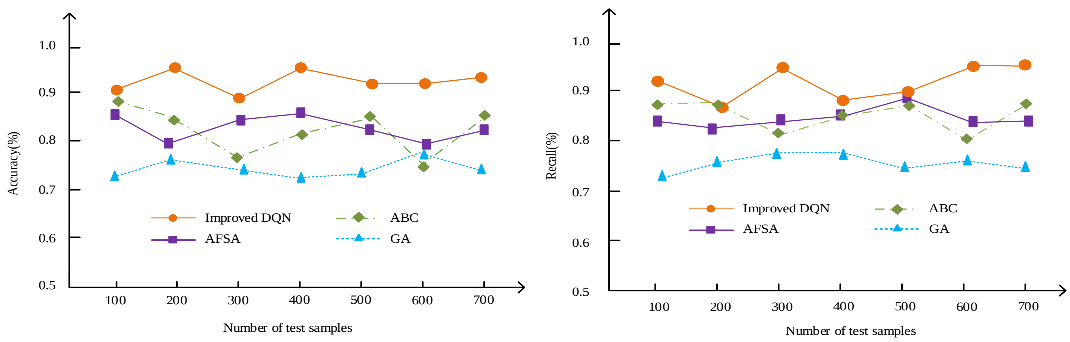


b) Data error situation after DQN network improvement.

Figure 8. Data extraction error effect before and after the improvement of DQN algorithm.

In Figure 8, the difference in data error results before and after the improvement of DQN algorithm is obvious. In Figure 8, the predicted error curve shown by the proposed algorithm in the process of data feature extraction has roughly the same trend as the actual error curve. It only has a 0.33% curve error fluctuation range with a small sample size, and its expected error range fluctuates at (-4,2). However, the improved DQN algorithm can improve the data extraction effect, and the difference between the measured value and the prediction is only 0.035%. And the error results are less disturbed by the change of sample size, which improves the performance of the algorithm to a certain extent. And the game algorithm was compared with Genetic Algorithm (GA) [1], Artificial Bee Colony (ABC) [23], and AFSA [25]. GA algorithm is an optimization algorithm based on natural selection and genetic mechanisms. It simulates the process of biological evolution, including operations such as selection, crossover, and mutation, to find the optimal solution. The ABC algorithm is an optimization algorithm that simulates the foraging behavior of bees. Bees work together to find the optimal solution while searching for food. AFSA algorithm is an optimization algorithm that simulates the foraging behavior of fish schools. Search for the optimal solution by simulating the foraging, gathering, and rear end behavior of fish schools. All three algorithms belong to swarm intelligence optimization algorithms, which rely on collaboration and information sharing among individuals to find the optimal solution. They all have global search capabilities and powerful optimization capabilities, and are suitable for various complex optimization problems. The goals in music rhythm teaching may include improving students' sense of rhythm, enhancing learning motivation and interest, etc., all of which are multi-objective optimization problems. GA, ABC, AFSA and other algorithms perform well in handling multi-objective optimization problems, and GA, ABC, AFSA algorithms can find solutions that are close to the optimal solution in a wide range of solution spaces, which is similar to DQN algorithm's need to explore and utilize strategies and paths in the state space in gaming environments. In music rhythm teaching, optimizing the effectiveness of gamified teaching and customizing personalized learning paths for students can also be seen as similar complex problems. Comparing the advantages and gaps between these algorithms and research methods can provide reference for improving music teaching to a certain extent. The results are shown in Figure 9.

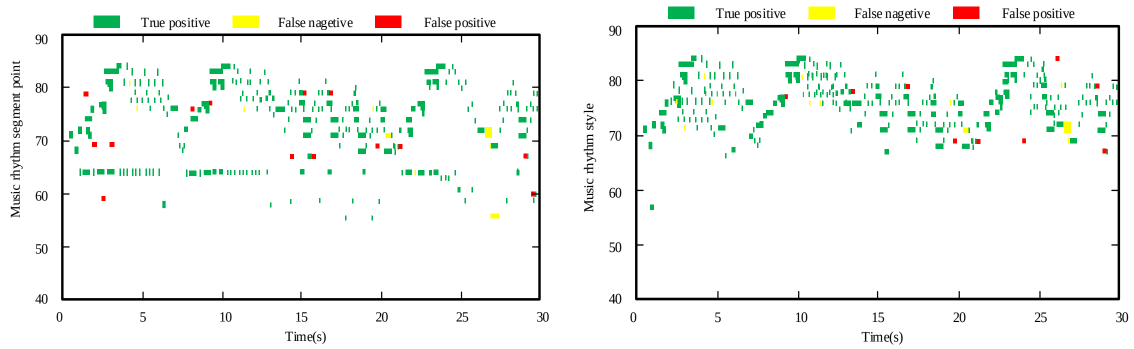
In Figure 9, the four algorithms mentioned above perform better in the game test, but there are still some gaps. For example, under the accuracy index, the improved DQN algorithm has the best performance, and the accuracy rate of the improved DQN algorithm is basically 90% or above. The relatively poor performance is GA algorithm. The accuracy of the improved DQN and AFSA algorithms can be maintained above 75%. The second is ABC algorithm, whose accuracy rate is more than 70%. But the fluctuation of curve change node is obvious. From the recall rate index, the improved DQN algorithm is also higher than that of AFSA, ABC and GA. The recall rate was able to stay above 82%. The worst performing algorithm is GA, which has a maximum difference of 12% between the improved DQN algorithm. The improved DQN algorithm has good accuracy, and its stability is good, and it can better cope with the change of the game scene. After that, the music rhythm evaluation results of the proposed game simulation algorithm were analyzed, and Figure 10 was obtained.



a) Single game scenario. b) Complex game scenes.

Figure 9. Accuracy and recall rate results of different algorithms.

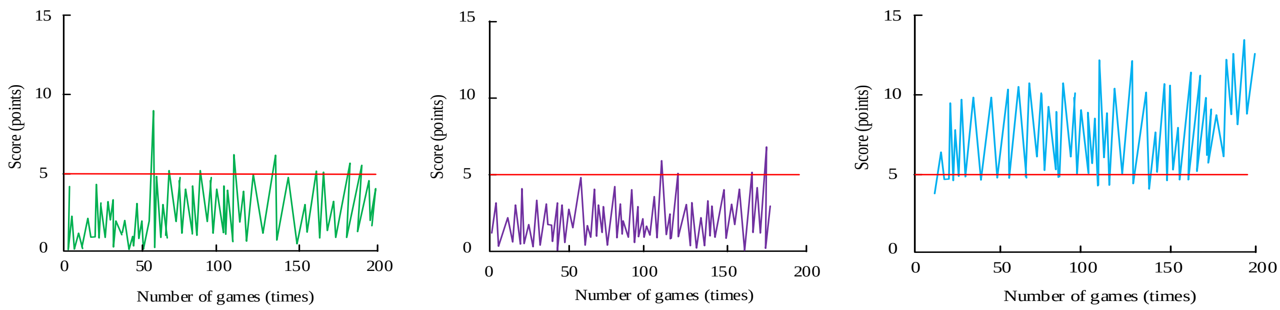
In Figure 10, the true value samples obtained by the improved DQN algorithm during music rhythm segment point recognition and music style recognition are significantly more than the detected value of the wrong sample, which is basically greater than 80; There were few false positive sample points, and the majority of true positive samples gathered. The improved DQN game algorithm can achieve better extraction of music rhythm, and its extraction accuracy exceeds 90%. There are few error detection and missing detection cases, and no obvious detection error cases. The performance of the improved DQN algorithm proposed in the research was evaluated in music games, and the results are shown in Figure 11.



a) Accuracy of music rhythm segment point recognition. b) Accuracy of music rhythm style recognition.

Figure 10. Music rhythm, speed and style recognition of improved DQN algorithm.

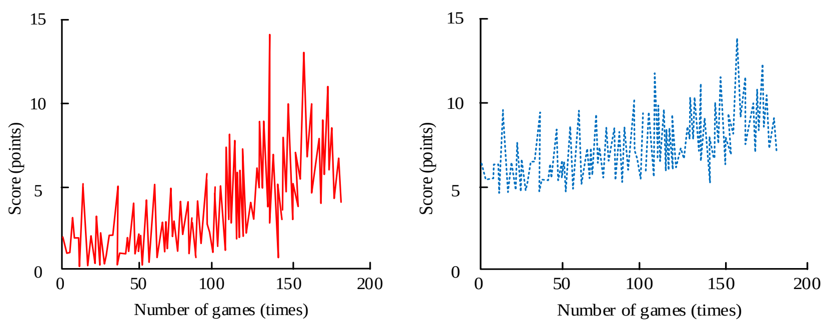
In Figure 10, the true value samples obtained by the improved DQN algorithm during music rhythm segment point recognition and music style recognition are significantly more than the detected value of the wrong sample, which is basically greater than 80; There were few false positive sample points, and the majority of true positive samples gathered. The improved DQN game algorithm can achieve better extraction of music rhythm, and its extraction accuracy exceeds 90%. There are few error detection and missing detection cases, and no obvious detection error cases. The performance of the improved DQN algorithm proposed in the research was evaluated in music games, and the results are shown in Figure 11.



a) ReLU function. b) Tanh function. c) Improved Activation function.

Figure 11. Scores of game simulation algorithms under different activation functions.

In Figure 11, the modified activation function used in the study showed a maximum game score of more than 10 points. With the increase of the number of games, the overall score showed an obvious increasing trend, and the overall value was higher than the benchmark. However, the scores of ReLu function and Tanh function are lower, and the scores of the two functions are basically hovering below 5 points. The overall score curve fluctuated significantly, with an average score of 3.6 and 2.7 points. Then, the improved filter is analyzed, and the results are shown in Figure 12.

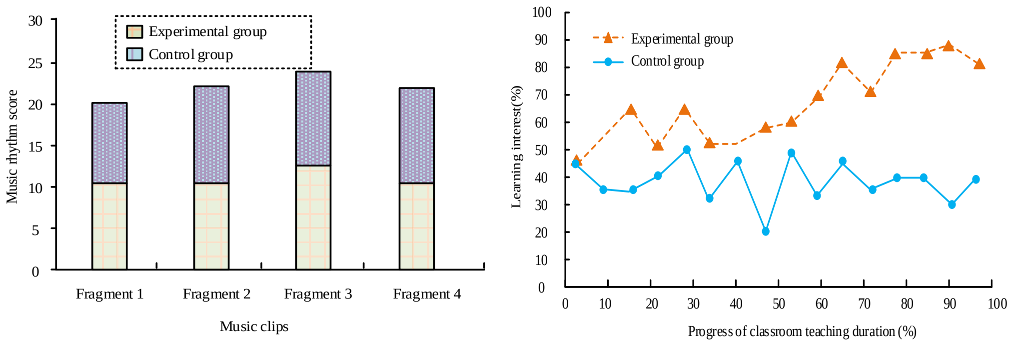


a) Before filter improvement. b) After improving the filter.

Figure 12. Algorithm scores before and after filter improvement.

In Figure 12, the algorithm after the filter improvement shows a significantly higher game score than the algorithm before the improvement. Moreover, the algorithm after dimensionality reduction has obvious effect on data processing, and the overall equilibrium state of the score curve is obvious. The score is basically in the range of (5~14), with the maximum score reaching 13 points. Games without the improved algorithm have lower scores, and the value change shows a large difference with different play times. The overall fluctuation is obvious, so the algorithm performance has a certain degree of instability.

Then, the proposed game simulation algorithm is tested for music rhythm teaching, and its applicability and effectiveness are analyzed. The study selected 160 students from three classes in the first year of junior high school as experimental subjects and invited them to participate in a music rhythm teaching experiment. The experimental subjects were randomly divided into a control group and an experimental group. The control group students will receive traditional music rhythm teaching, while the experimental group students will use a video game algorithm that integrates improved DQN network learning as an auxiliary tool to learn music rhythm on the basis of traditional teaching. The music classroom teaching content and frequency for the two groups of students are the same, with 2-3 sessions per week. Through the comparison and analysis of the learning performance and feedback data of the two groups of students, the application effect of video game algorithm integrating and improving DQN network learning in music rhythm teaching is explored. Figure 13 shows the learning situation of music rhythm determination and the change of learning interest of the two groups of students.



a) Score for music rhythm recognition.

b) Changes in learning interests.

Figure 13. Music rhythm judgment and learning interest results of the two groups of students.

In Figure 13, students in the experimental group using the game simulation algorithm scored higher than those in the control group in recognizing different segments of music rhythm, and there was a gap of at least 5 points between the experimental group and the control group. Meanwhile, the students in the experimental group showed more than 45% interest in learning under different duration of class, and there was no significant decline in interest in learning in the second half of class. It shows that this way of learning can better attract students' interest in learning. However, the students in the control group of traditional music teaching showed a recognition score of less than 15 points, and were more likely to suffer from learning weakness. Their highest interest in classroom learning was only 48%, and their lowest interest in classroom learning was 21%, and the gap between them and the experimental group became more prominent in the second half of the class. The improved DQN game algorithm shows good application effect in music rhythm teaching. The study analyzed the prosodic feature extraction effect of this algorithm for music signals, and the results were shown in Figure 14.

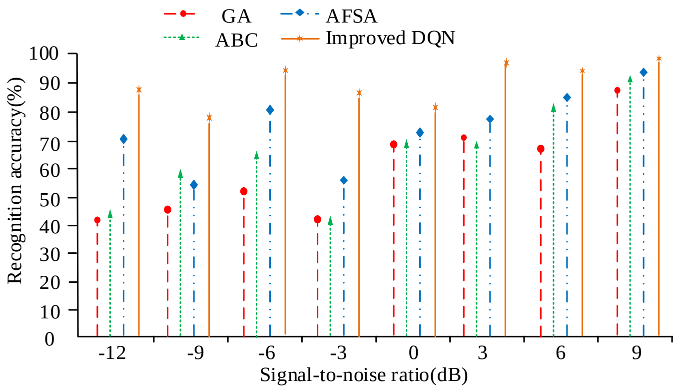
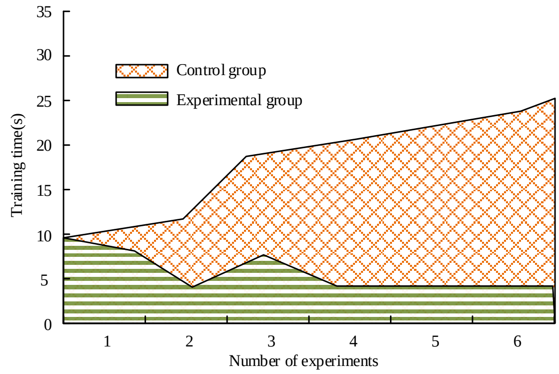
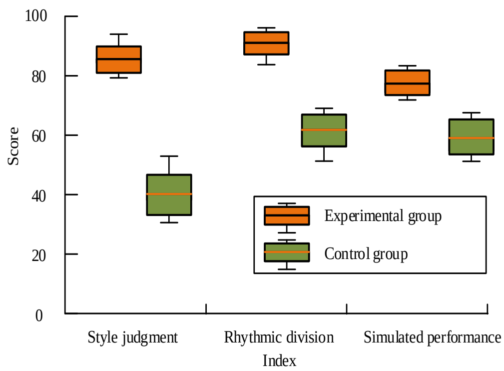


Figure 14. Analysis of the effect of different algorithms on prosodic feature extraction of music signals.

In Figure 14, under different Signal-to-Noise Ratio (SNR), different algorithms have great differences in the accuracy of music signal feature extraction. But in general, the recognition rate from low to high is as follows: improved DQN>AFSA>ABC>GA. The proposed algorithm can recognize the prosodic features of music signals well, and its recognition accuracy is more than 70%. It is less affected by the size of the signal-to-noise ratio and shows better performance. Then the students' learning results under the teaching method of applying game music rhythm were given feedback. By selecting a certain music examination material, students' test results and test time are counted to better support their performance in music teaching. The music test results are mainly based on students' performance in specific music exam materials, including mastery level and music skills. The test indicators include style judgment, rhythm division, and simulated performance. Specifically, the style judgment indicator is used to evaluate students' understanding and recognition ability of different music styles. Different types of music (such as classical, jazz, pop, etc.) present different style characteristics and rhythm expressions, which can measure students' sense of music and music recognition ability. Rhythm division is a key ability in music learning, which is used to evaluate whether students can accurately identify and divide rhythm patterns in music segments, understand and annotate the beginning and end of different beats, which is crucial for understanding music structure. Simulated performance tests students' ability to apply and create music rhythm, which is a reflection of comprehensive music performance and can reflect whether they can flexibly apply the learned content. The above test indicators can evaluate students' understanding and application ability of music rhythm from different perspectives, reflecting the effectiveness of music teaching. The results are shown in Figure 15.



a) Time consumption under music classroom testing.



b) Test scores under music classroom testing.

Figure 15. Test time and test results under the music classroom test.

In Figure 15, the experimental group of students using the improved DQN algorithm spent less time in the music rhythm recognition test, which was basically less than 10s; With the increase of the number of tests, the overall test time also showed a downward trend, and gradually tended to 4.3s in the late test period. In contrast, students in the control group spent a longer test time, reaching a maximum of 25s. The test results showed that the average scores of the students in the experimental group were 85 points, 90 points and 76 points in the three indicators of style judgment, rhythm division and simulated performance, which were much higher than the 40 points, 63 points and 60 points of the control group. Therefore, with the help of the improved algorithm proposed in the research, the teaching effect of music rhythm teaching can be better improved, and students can better grasp the teaching content.

5. Conclusions

This paper proposes to realize music rhythm teaching with video game algorithm, and improves the original DQN network, that is, based on considering the characteristics of music teaching, the fusion algorithm is used for analysis. Through the application analysis of the algorithm, the difference range of the game algorithm designed in the research is only 0.035% when extracting data features, and the error results are less disturbed by the change of sample size. Its algorithm accuracy is basically 90% or above, higher than AFSA (75%) and ABC (70%). The recall rate is more than 82%, and the maximum difference between GA algorithm and GA algorithm is 12%. The extraction accuracy of the improved DQN algorithm is more than 90% in the recognition of rhythm segment and music style. Its overall performance of the game score is better, with higher performance. Meanwhile, the game simulation algorithm has a higher recognition score for different parts of music rhythm than the traditional teaching method (the difference is more than 5 points). Students showed more than 45% interest in learning. The students under traditional music teaching scored no more than 15 points for rhythm recognition, and the maximum learning interest was only 48%. The improved algorithm can extract music signal features well, the recognition accuracy is more than 70%, and the influence of SNR is small. In addition, the time division of music rhythm recognition of students under this teaching method is basically less than 10s, and gradually tends to 4.3s in the later stage of the test. The average scores of the students in the three indexes of style judgment, rhythm division and simulated performance were 85, 90, and 76 points respectively, which were much higher than the 40, 63, and 60 points of the control group. The improved DQN algorithm proposed in the research can effectively realize the game simulation, and has a good recognition rate and applicability to music rhythm teaching. Strengthening the application effect of the game simulation algorithm in different scenarios is the aspect that needs attention in future research.

Conflicts of Interests

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.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

References

[1] Albaghajati A. and Ahmed M., “Video Game Automated Testing Approaches: An Assessment Framework,” *IEEE Transactions on Games*, vol. 15, no. 1, pp. 81-94, 2020. https://doi.org/10.1109/TG.2020.3032796

[2] Bharati S., Khan T., Podder P., and Huang N., *Cognitive Internet of Medical Things for Smart Healthcare: Services and Applications*, Springer, 2021. https://link.springer.com/chapter/10.1007/978-3-030-55833-8_3

[3] Chen G., Cai Q., Fu X., and Lai Y., “Research on Algorithms of Computing Offloading and Resource Allocation Based on DQN,” *in Proceedings of the 5th International Seminar on Computer Technology, Mechanical and Electrical Engineering*, Shenyang, pp. 032047-032048, 2020. DOI:10.1088/1742-6596/1748/3/032047

[4] Dai Z., “Research on Network Intrusion Detection Security Based on Improved Extreme Learning Algorithms and Neural Network Algorithms,” *International Journal of Biometrics*, vol. 12, no. 1, pp. 56-57, 2020. https://doi.org/10.1504/IJBM.2020.10027201

[5] Dakshayani V., Locharla G., Plawiak P., Datti V., and Karri C., “Design of a Gabor Filter-Based Image Denoising Hardware Model,” *Electronics*, vol. 11, no. 7, pp. 1063, 2022. https://doi.org/10.3390/electronics11071063

[6] Fuchs J., Isenberg P., Bezerianos A., Miller M., and Keim D., “Teaching Clustering Algorithms with EduClust: Experience Report and Future Directions,” *IEEE Computer Graphics and Applications*, vol. 40, no. 2, pp. 98-102, 2020. https://doi.org/10.1109/MCG.2020.2970560

[7] Gaina R., Devlin S., Lucas S., and Perez-Liebana D., “Rolling Horizon Evolutionary Algorithms for General Video Game Playing,” *IEEE Transactions on Games*, vol. 14, no. 2, pp. 232-242, 2021. https://doi.org/10.48550/arXiv.2003.12331

[8] Ganghua B., “Simulation of Performance Skills Teaching System Based on Machine Vision and Sensor Audio Signal Processing,” *Measurement: Sensors*, vol. 33, pp. 101224, 2024. https://doi.org/10.1016/j.measen.2024.101224

[9] Grekow J., “Music Emotion Recognition Using Recurrent Neural Networks and Pretrained Models,” *Journal of Intelligent Information Systems*, vol. 57, no. 3, pp. 531-546, 2021. https://doi.org/10.1007/s10844-021-00658-5

[10] Huang Y., Lin W., and Chen Q., “Music Video Therapy Can be an Effective Nonpharmaceutical Intervention in Relieving Children’s Postoperative Pain After Cardiothoracic Surgery,” *Journal of Cardiac Surgery*, vol. 37, no. 1, pp. 261-261, 2022. https://doi.org/10.1111/jocs.16114

[11] James L. and Reifinger J., “Teaching Pitch Notation-Reading Skills,” *General Music Today*, vol. 33, no. 3, pp. 21-28, 2019. https://doi.org/10.1177/1048371319891419

[12] Jiang H., Zhang H., Xie X., and Han J., “Neural-Network-Based Learning Algorithms for Cooperative Games of Discrete-Time Multi-Player Systems with Control Constraints Via Adaptive Dynamic Programming,” Neurocomputing, vol. 344, no. 7, pp. 13-19, 2019. https://doi.org/10.1016/j.neucom.2018.02.107

[13] Karamizadeh S., Abdullah S., Manaf A., Zamani M., and Hooman A., “An Overview of Principal Component Analysis,” *Journal of Signal and Information Processing*, vol. 4, no. 3, pp. 2159-4481, 2020. https://doi.org/10.4236/jsip.2013.43B031

[14] Khan A., Feng J., Liu S., and Omara I., “Playing a FPS Doom Video Game with Deep Visual Reinforcement Learning,” *Automatic Control and Computer Sciences*, vol. 53, no. 3, pp. 214-222, 2019. https://doi.org/10.3103/S0146411619030052

[15] Lipsky M. and Kantor J., “Identification of Challenges and Strengths of Children with Special Educational Needs in Their Musical Improvisations,” *Journal of Clinical Psychology and Special Education*, vol. 8, no. 1, pp. 118-136, 2019. https://doi.org/10.17759/cpse.2019080108

[16] Mateo C. and Talavera J., “Bridging the Gap between the Short-Time Fourier Transform (STFT), Wavelets, the Constant-Q Transform and Multi-Resolution STFT,” *Signal Image and Video Processing*, vol. 14, no. 8, pp. 1535-1543, 2020. https://doi.org/10.1007/s11760-020-01701-8

[17] Meng Z. and Chen W., “Automatic Music Transcription Based on Convolutional Neural Network, Constant Q Transform and MFCC,” *in Proceedings of the 2nd International Conference on Artificial Intelligence Technologies and Application*, Dalian, pp. 1-9, 2020. https://doi.org/10.1088/1742-6596/1651/1/012192

[18] Mor B., Garhwal S., and Kumar A., “A Systematic

Review of Hidden Markov Models and Their Applications," *Archives of Computational Methods in Engineering*, vol. 28, pp. 1429-1448, 2021. https://doi.org/10.1007/s11831-020-09422-4

[19] Muller M., McFee B., and Kinnaird K., "Interactive Learning of Signal Processing Through Music: Making Fourier Analysis Concrete for Students," *IEEE Signal Process Magazine*, vol. 38, no. 3, pp. 73-84. 2021. https://doi.org/10.1109/MSP.2021.3052181

[20] Petersen P. and Voigtlaender F., "Optimal Approximation of Piecewise Smooth Functions Using Deep ReLU Neural Networks," *Neural Networks*, vol. 108, pp. 296-330, 2018. https://doi.org/10.1016/j.neunet.2018.08.019

[21] Raj P., Reddy P., and Chandrachoodan N., "Reduced Memory Viterbi Decoding for Hardware-Accelerated Speech Recognition," *ACM Transactions on Embedded Computing Systems*, vol. 21, no. 3, pp. 1-18, 2022. https://doi.org/10.1145/3510028

[22] Borges A. and Richit A., "Development of Teaching Knowledge to Teach Music in Elementary School," *Cadernos De Pesquisa*, vol. 50, no. 176, pp. 555-574, 2020. https://doi.org/10.1590/198053146782

[23] Saeidi S., "A New Model for Calculating the Maximum Trust in Online Social Networks and Solving by Artificial Bee Colony Algorithm," *Computational Social Networks*, vol. 7, no. 1, pp. 3, 2020. https://doi.org/10.1186/s40649-020-00077-6

[24] Smerdov A., Somov A., Burnaev E., Zhou B., and Lukowicz P., "Detecting Video Game Player Burnout with the Use of Sensor Data and Machine Learning," *IEEE Internet of Things Journal*, vol. 8, no. 22, pp. 16680-16691, 2021. https://doi.org/10.48550/arXiv.2012.02299.

[25] Tian Y., Li Y., Pan L., and Harry M., "Research on Group Animation Design Technology Based on Artificial Fish Swarm Algorithm," *Journal of Intelligent and Fuzzy Systems*, vol. 38, no. 2, pp. 1137-1145, 2020. https://doi.org/.10.3233/JIFS-179475

[26] Wang Y., Mao M., Chang L., and Hatziargyriou N., "Intelligent Voltage Control Method in Active Distribution Networks Based on Averaged Weighted Double Deep Q-Network Algorithm," *Journal of Modern Power Systems and Clean Energy*, vol. 11, no. 1, pp. 132-143, 2023. https://doi.org/10.35833/MPCE.2022.000146

[27] Yang Y. and Song X., "Research on Face Intelligent Perception Technology Integrating Deep Learning Under Different Illumination Intensities," *Journal of Computational and Cognitive Engineering*, vol. 1, no. 1, pp. 32-36, 2022. https://doi.org/10.47852/bonviewJCCE19919

[28] Yi G., "Teaching about the Korean Ganggangsullae Folk Tradition in General Music Class," *Music Educators Journal*, vol. 105, no. 3, pp. 45-53, 2019. https://doi.org/10.1177/0027432118815961

[29] Yu X., Ye C., Li B., Zhou H., and Huang M., "A Deep Q-Learning Network for Dynamic Constraint-Satisfied Service Composition," *International Journal of Web Services Research*, vol. 17, no. 4, pp. 55-75, 2020. https://doi.org/10.4018/IJWSR.2020100104

[30] Zalkow F., Balke S., Arifi-Müller V., and Müller M., "MTD: A Multimodal Dataset of Musical Themes for MIR Research," *International Society for Music Information Retrieval*, vol. 3, no. 1, pp. 180-192, 2020. https://doi.org/.10.5334/tismir.68

[31] Zeng D., Yan T., Zeng Z., Liu H., and Guan P., "A Hyperparameter Adaptive Genetic Algorithm Based on DQN," *Journal of Circuits, Systems and Computers*, vol. 32, no. 4, pp. 2350062, 2023. https://doi.org/10.1142/S0218126623500627

[32] Zeng M., "Gesture Recognition Technology of VR Piano Playing Teaching Game based on Hidden Markov Model," *International Arab Journal on Information Technology*, vol. 21, no. 4, pp. 760-772, 2024. https://doi.org/10.34028/iajit/21/4/15

[33] Zhang Z., Zhang Q., Miao J., Yu F R., Fu F., Du J., and Wu T., "Energy-efficient secure video streaming in UAV-enabled wireless networks: A safe-DQN approach," *IEEE Transactions on Green Communications and Networking*, vol. 5, no. 4, pp. 1892-1905, 2021. https://doi.org/10.1109/TGCN.2021.3095315

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