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Piano Automatic Computer Composition by Deep Learning and Blockchain Technology

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ABSTRACT To explore the automatic computer composition, investigate the copyright protection and management of digital music, and expand the application of deep learning and blockchain technologies in the generation of digital music works, piano composition was taken as a sample. First, through the elaboration of the neural network methods based on deep learning, the Recurrent Neural Network (RNN), Long-Short-Term Memory (LSTM), and Gated Recurrent Unit (GRU) networks were introduced, and the deep learning-based GRU-RNN automatic composition model was constructed. Second, the blockchain technology was analyzed and expressed, and the problems in the traditional copyright protection and management of digital music were analyzed. The three aspects, i.e., ownership, right of use, and right protection, were fully considered, and the blockchain technology was integrated into the copyright protection and management of digital music. Finally, the manual analysis evaluation and pause analysis were selected as the indicators to analyze and characterize the music composition quality of the GRU-RNN model, as well as analyzing the development of the digital music market integrated with blockchain technology. The results show that the GRU-RNN model shows satisfactory effects in manual analysis evaluation or in the pause analysis of the passage. The deep learning method has great potential for application in automatic computer composition of digital music; the integration of blockchain technology has played a promotive role in the expansion and popularization of the digital music market. However, in the meantime, it still faces some technical and policy challenges. The results have a positive effect on promoting the development and application of deep learning methods and blockchain technology in digital music.

INDEX TERMS GRU-RNN, LSTM, automatic composition, digital music, blockchain technology, copyright protection and management.

I. INTRODUCTION

Due to the rapid economic development and the continuous improvement of living standards, the demand for the public for spiritual culture continue to increase, accompanied by the improvement of appreciation. Music art can express emotions and resonate, and it has played an influential role in the past, especially in contemporary society [1], [2]. In the field of music and art, piano has a wealth of musical theory expression ability, which is a key category in this field [3], [4]. In the generation of piano music, manual music composition puts high demands on professional knowledge, such as precise mastery of music theory and harmony. Only a person with complete music knowledge reserve can create qualified music scores. However, for the average participating users, the lack of professionalism makes it harder for them to complete the composition. The development of big data technology, machine learning, and the mobile Internet have made it possible to compose music automatically. Reference [5] described a scalable composite music generator that could be used for emotional music creation, where melody generation utilized the multi-objective optimization technology; it was found that the music generation system made the perceived quality of each piece of produced music improved; at the same time, the system could reliably generate emotionally rich music and achieve the creation of adaptive dynamic soundtracks [5]. Reference [6] explored data musicalization and analyzed the data musicalization methods, providing an electronic sample of music generated by different musicalization applications; even ordinary users could create music pieces [6]. Reference [7] explored the automatic emotion labeling of music video clips; by using electroencephalography (EEG), it was found that the proposed features could play an influential role in describing the importance of human emotional state

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when watching music clips [7]. Reference [8] introduced the interactive sound framework of big data technology in music creation, which provided a reference for the application of social media and the Internet of Things in musical instruments [8]. In summary, research on automation in the field of music has been involved and has achieved some research results. However, there is not much research on applying deep learning methods, and research results on automatic composition are few.

In the field of music and art, attention should be paid to the copyright protection and management of musical works. The continuous innovation and development of new technological methods are critical in promoting the development of the music industry. Among these technologies, blockchain technology is an existence that cannot be ignored. At present, blockchain technology has been applied in many fields. Reference [9] explored the application of blockchain technology associated with the fourth industrial revolution; it was found that blockchain technology could play a huge role in promoting machine interaction and establishing electricity markets [9]. Reference [10] applied blockchain technology to clinical trials and found that the application of this technology could ensure data security and fine-grained control of shared parameters [10]. In summary, it is evident that blockchain technology has application potential in many fields, but there are fewer research works on applying this technology to digital music.

On this basis, the application of blockchain technology in digital music copyright management was explored, thereby studying the automatic computer composition based on deep learning and expanding the application of modern intelligent algorithms and technologies in the field of music art. The Recurrent Neural Network (RNN) model and the blockchain technology were introduced to provide a reference for the development of digital music.

II. METHOD

A. NEURAL NETWORKS BASED ON DEEP LEARNING

With the rapid development of computer technology and artificial intelligence (AI) technology in various fields, machine learning is also developing rapidly. Deep learning is a key technical means to achieve AI in machine learning, and the performance of deep learning in practical applications is significantly better than other commonly used machine learning methods; the main reason is that deep learning can extract effective features from massive data information, which makes it capable of being widely used [11]–[13]. From the perspective of the neural networks, the application of deep learning has solved the problems that the neural networks show in optimization and calculation. In recent years, in the field of deep learning, neural network models have been widely used.

Actually, the neural network is a large-scale processor. Its simulation of the brain is mainly completed by learning knowledge and storing knowledge. This technology was originally proposed in the 1940s. In addition to the increasing popularity of the Internet in recent years, the application scope of neural networks has been expanded and extended further. In terms of structural composition, the neural network is composed of an input layer, an intermediate layer, and an output layer. The connection between the various constituent structures is achieved by weights. At the same time, the connection weight between the various constituent structures is obtained by weights, and the obtaining of connection weights between the various constituent structures is mainly achieved by training the error back propagation algorithm [14], [15]. The composition of the neural network can be represented by Figure 1.

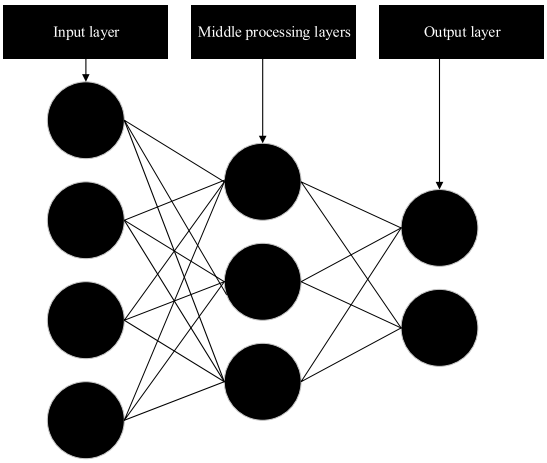

FIGURE 1. Neural network structure.

B. CONSTRUCTION OF AUTOMATIC COMPOSITION MODEL BASED ON RNN

From the perspective of music composition, piano music can be regarded as a sequence composed of multiple notes; this sequence is formed according to the relevant music theory rules, and each component note is dependent. Recurrent Neural Network (RNN) is one of the neural network models. Compared with other common feedforward neural networks, there are more feedback links between hidden layers in RNN [16], [17]. The output layer o_t in the RNN can be expressed as:

$$o_t = \varphi(Vs_t) \tag{1}$$

$$s_t = f(Ux_t + Ws_{t-1}) \tag{2}$$

where, V represents the weight matrix corresponding to the hidden layer to the output layer, s_t represents the output value corresponding to the hidden layer, U represents the weight matrix from the input layer to the hidden layer, x_t represents the value corresponding to the input layer, Ws_{t-1} represents the influence weight, and s_{t-1} represents the state output of the hidden layer at time $t-1$.

Combining the above two equations, the following will be obtained:

$$o_t = \varphi(VfUx_t + Wf(Ux_{t-1} + Wf(Ux_{t-2} + Wf(Ux_{t-3} + Ws_{t-4})))) \tag{3}$$

The above equation indicates that the output value corresponding to the RNN is closely related to the output value corresponding to it. This fact also shows that the memory function of the RNN has, so the RNN has positive effects on the solution to the sequence-related problems at the same time. The process of piano automatic composition is similar to the input and output of the RNN; the prediction is also based on the corresponding note sequence. Therefore, RNN is chosen as the basis for piano automatic composition.

Although the RNN model shows excellent performance in time series problems, the neural network model also has problems such as gradient explosion or gradient disappearance. On this basis, to avoid the limitations of the RNN in terms of gradients, the Long-Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) are introduced. The special feature of the LSTM network is the introduction of gate mechanism so that the information transmission path can be regulated [18]. Based on the objective of optimizing RNN, a total of three gates, i.e., the Input Gate i_t, the Forget Gate f_t, and the Output Gate o_t, are introduced into LSTM. At the same time, an internal state c_t that can realize the linear transmission of information is introduced. Among them, the Forget Gate can be expressed as:

$$f_t = \sigma\left(W_f \cdot [h_{t-1}, x_t] + b_f\right) \tag{4}$$

where, W_f represents the weight matrix, b_f represents the paranoid term, x_t represents the input value at the corresponding time, and h_{t-1} represents the external state at the previous time. The Input Gate can be expressed as:

$$i_t = \sigma\left(W_i \cdot [h_{t-1}, x_t] + b_i\right) \tag{5}$$

where, W represents the weight matrix corresponding to the Input Gate, and b_i represents the paranoid term corresponding to the Input Gate.

The Output Gate can be expressed as:

$$o_t = \sigma\left(W_o \cdot [h_{t-1}, x_t] + b_0\right) \tag{6}$$

where, W_o represents the weight matrix corresponding to the Output Gate, and b_0 represents the paranoid term corresponding to the Output Gate.

For the state $\widetilde{c}_t$, the corresponding equation expression and calculation can be expressed as:

$$\widetilde{c}_t = \tanh\left(W_c \cdot [h_{t-1}, x_t] + b_c\right) \tag{7}$$

where, $\widetilde{c}_t$ represents the state inside at the moment. For the LSTM network, the final corresponding output is the result of the combined action of o_t and c_t, which can be expressed as:

$$h_t = o_t \odot \tanh\left(c_t\right) \tag{8}$$

Through the introduction of the LSTM network, some invalid information can be removed; at the same time, the preservation of the valid information is realized so that the performance of the RNN can be improved further.

Compared to LSTM, the GRU network has a simpler structure. The network is mainly composed of an Update Gate z_t and a Reset Gate r_t [19], [20], where the equation expression and calculation of the Update Gate z_t is:

$$z_t = \sigma\left(W^{(z)} x_t + U^{(z)} h_{t-1}\right) \tag{9}$$

where, $x_t W^{(z)}$ represents the input vector, $W^{(z)}$ and $U^{(z)}$ represent the weight matrix.

The equation expression and calculation of the Reset Gate r_t can be expressed as:

$$r_t = \sigma\left(W^{(r)} x_t + U^{(r)} h_{t-1}\right) \tag{10}$$

In this network, the equation expression and calculation of the corresponding candidate state $\widetilde{h}_t$ at the current moment is:

$$\widetilde{h}_t = \tanh\left(W x_t + r_t \odot U h_{t-1}\right) \tag{11}$$

where, x_t represents the input vector, h_{t-1} represents the candidate state corresponding to the previous moment, W and U represent the weight matrix.

Corresponding to the final output of the network, the update in the current state h_t can be expressed as:

$$h_t = z_t \odot h_{t-1} + (1 - z_t) \odot \widetilde{h}_t \tag{12}$$

In summary, the introduction of "gate mechanism" can play an influential role in processing long-term dependence problems. Here, the focus is applying GRU network to piano automatic computer composition. The entire automatic composition process of piano can be divided into neural network model training based on note sequence data set and neural network model prediction based on note. The GRU network is introduced into it, and the note sequence data set is defined as:

$$Notes = [note_1, note_2, note_3, \cdots\cdots, note_t] \tag{13}$$

Furthermore, the set of notes input from the network can be defined as:

$$X = \begin{bmatrix} note_1 & note_2 & note_3 & \cdots & note_n \\ note_2 & note_3 & note_4 & \cdots & note_{n+1} \\ note_3 & note_4 & note_5 & \cdots & note_{n+2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ note_m & note_{m+1} & note_{m+2} & \cdots & note_{m+n} \end{bmatrix} \tag{14}$$

The expected set of notes on the network can be defined as:

$$R = \begin{bmatrix} note_{n+1} \\ note_{n+2} \\ note_{n+3} \\ \vdots \\ note_{n+m+1} \end{bmatrix} \tag{15}$$

The generated note set corresponding to the prediction network model can be expressed as:

$$Y = \begin{bmatrix} note\_pre_1 \\ note\_pre_2 \\ note\_pre_3 \\ \vdots \\ note\_pre_m \end{bmatrix} \tag{16}$$

The softmax function is utilized to calculate the output note, the corresponding equation expression and calculation is:

$$soft\max\left(u_j\right) = \frac{\exp\left(u_j\right)}{\sum_{q=1}^{k} u_q} \tag{17}$$

where, u_j represents the activation value corresponding to the j-th unit in the network output layer.

After the i-th training process, the actual predicted notes and expected output notes can be finally obtained; then, the error can be solved by the cross entropy loss function, and the weights can be updated by the error back propagation algorithm to optimize the network structure. The corresponding training process of the piano automatic composition neural network model and the realization of the automatic composition process are shown in Figure 2 below. The piano automatic composition neural network model is recorded as GRU-RNN.

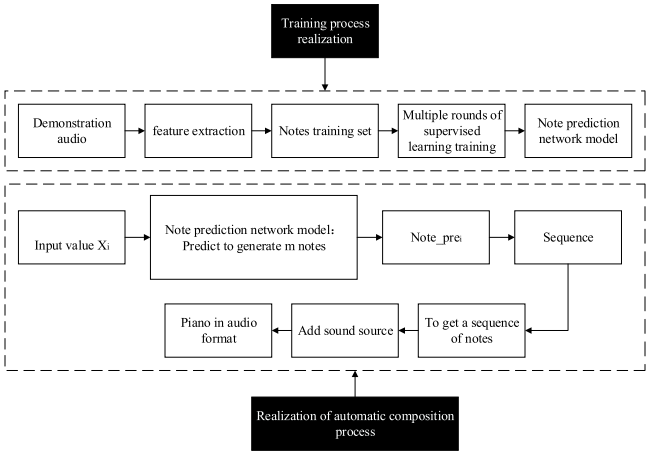

FIGURE 2. Neural network model training process of piano automatic composition and realization of automatic composition process.

C. BLOCKCHAIN TECHNOLOGY

Specifically, the so-called blockchain technology refers to a technology that can realize data storage, data update, data transmission, and data access. Precisely, the technology is a distributed database system that applies cryptography technology, where the various constituent blocks are connected to each other to form a chain structure [21]. Blockchain technology has the characteristics of decentralization in the way of networking, and the characteristics of de-trusting in the way of formation; in addition, it also applies consensus algorithms and encryption algorithms. In terms of development process, blockchain technology has been used largely in digital currency initially. With its development, its application field has gradually expanded. Currently, it has been applied in various fields including finance, culture, art, and government [22]. Essentially, the blockchain has the characteristics of openness and transparency. For example, in the field of logistics, the application of blockchain technology can facilitate the simplification of the steps of the logistics chain and avoid the occurrence of counterfeit goods. In the field of supply chain finance, the application of blockchain technology can promote the improvement of efficiency and the reduction of risk so that the transparency of information flow can be increased to some extent. In the field of cross-regional payment, the application of blockchain technology can promote the shortening of the cycle, which can complete the construction of the trust mechanism. In the field of information sharing, the application of blockchain technology can promote the improvement of safety and security, thereby promoting the development of the sharing economy. In addition, in the art field including music composition and copyright protection, the application of blockchain technology can improve the corresponding protection mechanism and prevent the occurrence of infringement. The composition of application areas involved in blockchain technology is shown in Figure 3 below.

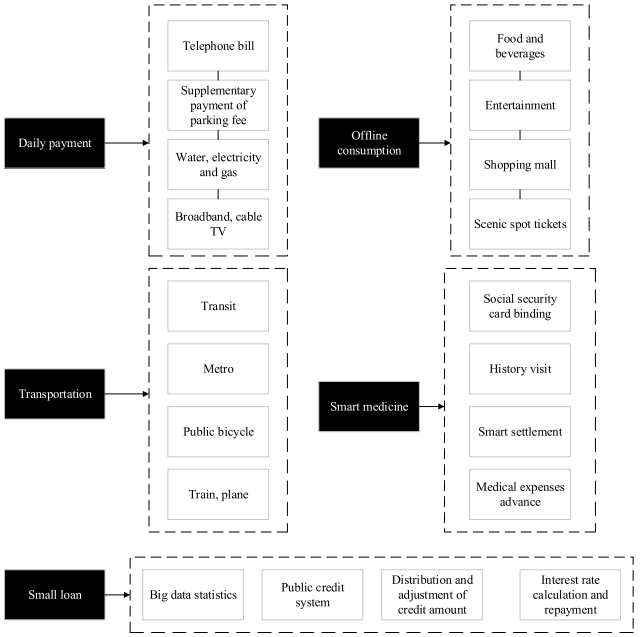

FIGURE 3. Application areas of blockchain technology.

In summary, it is obvious that the excellent characteristics of blockchain technology make this technology applicable in many technical fields. For the completion of music compositions, the protection of its copyright is also very important. For this reason, the blockchain technology will be applied to the copyright protection and management of computer-based digital musical contents.

D. CONSTRUCTION OF DIGITAL MUSIC MANAGEMENT SYSTEM BASED ON BLOCKCHAIN TECHNOLOGY

With the rapid development of multimedia networks, digital music has emerged and developed rapidly in the field of music. From the aspect of existence form, its composition form is digital. The digital music can be spread through the

network, and at the same time, the quality of the music itself can be guaranteed, which is also an important reason that digital music is more competitive in the market. Similar to traditional music, the copyright of digital music is protected, and its copyright belongs to the owner of the original musical work.

For traditional digital music, the copyright registration process is carried out mainly in two ways. First, the copyright is automatically obtained at the same time as the musical work is generated; second, it can be obtained after the registration of the relevant responsible department. The copyright registration of digital works can play an important role in tracking copyright records and promoting the resolution of infringement issues.

For the copyright of digital music works, a complete management system is not only beneficial to the construction of the digital music market but also the protection of intellectual achievements and interests. As for the protection and management of the copyrights of digital music works, there are still some problems; specifically, the manifestation is the imperfection of laws and regulations related to digital music copyright. This is mainly because that with the continuous innovation of technology, the traditional management methods are no longer applicable; however, the relevant liability has not been adjusted for this, resulting in the occurrence of undesirable phenomena such as piracy; in addition, the public does not pay enough attention to the protection of copyright, making copyright management more difficult. Besides, the traditional digital music registration process is cumbersome and consumes a lot of costs. For the protection and management of copyright, many detection tools are needed, which makes the efficiency of copyright protection and management for digital music works poor.

With the continuous development and innovation of blockchain technology, new direction and assistance are provided for the protection and management of the copyright of digital music works. Here, the blockchain technology is applied to the copyright protection and management of digital music works. The construction of the digital music management system mainly includes the stages of confirming the copyright ownership, copyright use, and rights maintenance. In the stage of confirming the copyright, the personal information of the owner of the corresponding music work and the music itself are stored in the blockchain with the help of blockchain technology. In this process, combined with the principles of cryptography, the unique digital authentication DNA of digital music works can be generated. The verification of digital rights is completed with the help of public and private keys. By applying smart contracts, the copyright holders of digital music works can be informed and pay the corresponding fees in time. The copyright use stage is the core link of the entire system construction. At this stage, the focus is copyright use, which is of great significance for promoting the circulation of digital music works and extending the life cycle of related works; therefore, digital music works based on blockchain technology can obtain greater economic benefits. By applying the blockchain technology to the copyright management and protection of digital music works, because the relevant information is stored in the blockchain, the relevant copyright information of digital music works can be jointly managed by each constituent node. If infringement occurs, the information stored in the blockchain will be used as the basis for rights protection so that the problem can be solved from the source. In summary, the digital music copyright protection and management system integrated with blockchain technology is constructed, as shown in Figure 4 below.

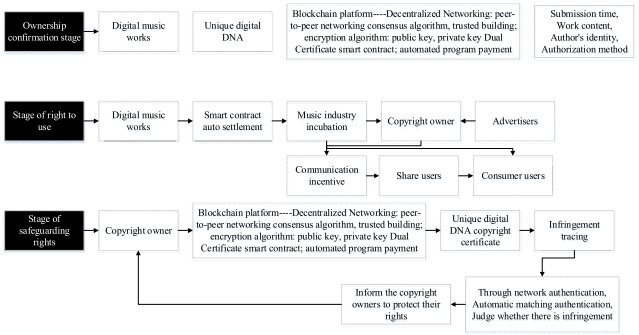

FIGURE 4. Digital music copyright protection and management system integrated with blockchain technology.

Furthermore, based on ownership confirmation, power use, the digital music copyright registration and transaction based on blockchain technology are incorporated, as well as the digital music copyright management and protection mechanism. Also, the impacts of the expansion of the digital music market in recent years, as well as the integration of blockchain technology on the digital music works of automatic computer composition completed by pianos, are analyzed and characterized.

E. EXPERIMENTAL DESIGN

For the evaluation of piano automatic computer composition quality, considering the large amount of data involved in the neural network model training process, during the training process, the software and hardware configuration of the experimental design is shown in Table 1 below.

In this experimental design, a total of 9,850 pieces of music were selected as the training data. Among them, 2,820 pieces of music were used to adjust the model and the rest were used to verify the model. The hidden layer in the neural network model was set to 254. The cross entropy was utilized as the loss function, and the stochastic gradient descent method was employed to complete the update processing of the relevant parameters. For the characterization of the proposed piano learning composition model based on deep learning, the manual analysis and passage pause evaluation were selected. Besides, it was compared with the music composition generation model GAN-Midi (music composition generation model based on confrontation generation network) and Magenta (RNN) (music composition generation

TABLE 1. Software and hardware configuration of experimental design.

Hardware configuration		Software configuration	
Detailed configuration	Composition	Function	Corresponding software
Central processing unit	Intel i7-7800X	Deep learning framework	TensorFlow 1.12
Graphic Processing Unit	GeForce RTX 2080	Network implementation	Python 3.7
Random access memory	32GB	Front end frame	React 16.8.4

model based on RNN). In manual analysis and evaluation, the melody, rhythm, completeness and singability were utilized as evaluation indicators. In the analysis of pauses in the passages, the distribution of the passages of different lengths and the distribution of different lengths of actual music were used as evaluation indicators. Specifically, the actual music was represented by the suffix -g.

III. RESULTS

A. EVALUATION RESULTS OF GRU-RNN MODEL

Through the utilization of manual analysis and evaluation methods, the comparison and evaluation results of the GRU-RNN model with the GAN-Midi and Magenta (RNN) methods are shown in Figure 5 below.

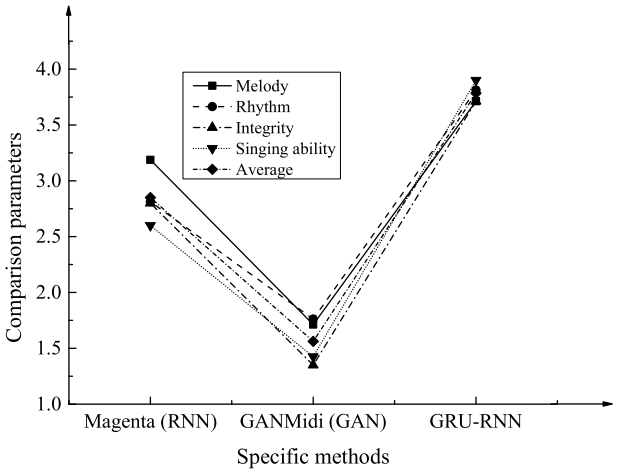

FIGURE 5. Comparison results based on manual analysis and evaluation.

As shown in data changes including melody, rhythm, completeness, and singability in Figure 5, the proposed GRU-RNN model based on deep learning shows the best results in all aspects, which are specifically as follows: the score of the melody component is 3.8126, the score of the rhythm component is 3.7124, the score of the integrity component is 3.7124, and the score of singability component is 3.9001. The average score is 3.7844. Compared with other automatic composition generation methods, it shows better results.

The GRU-RNN model is applied to the piano automatic computer composition generation. The minimum, average, and maximum values are used as evaluation indicators. The distribution and changes of the composition sections with actual lengths and the corresponding sections of the actual music are different, as shown in Figure 6 below.

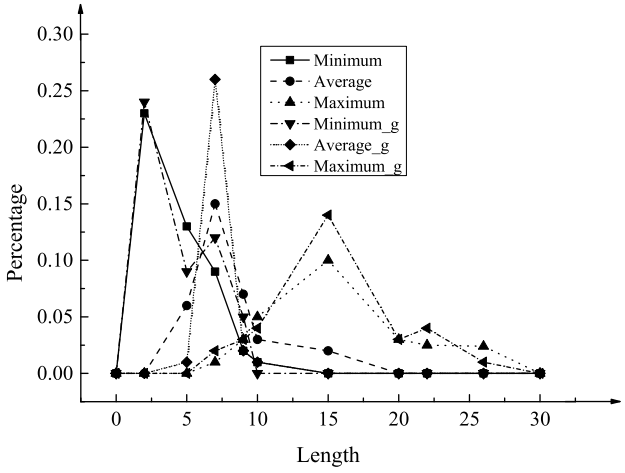

FIGURE 6. The distribution and change of passages with different lengths (in the figure, the suffix -g indicates the distribution change corresponding to the real music passage).

After the data changes in Figure 6 were analyzed, depending on the pauses, each component segment of the music can be divided. It is not difficult to discover that the application of the GRU-RNN model makes the distribution of music composition and actual music have similar distribution changes in the length of the segment. This shows that the GRU-RNN model can master the pause of the corresponding passage in the music so that the structural characteristics of the music can be well maintained.

B. DIGITAL MUSIC MANAGEMENT INTEGRATED WITH BLOCKCHAIN TECHNOLOGY

Through the incorporation of blockchain technology, the statistics of the market size and growth rate of digital music in 2013-2019 and the prediction of the market size and growth rate of digital music from 2020 to 2023 are shown in Figure 7 below.

According to the analysis of the data changes shown in Figure 7, the market size of digital music has been increasing since 2013. However, in terms of growth rate, the market size growth rate is the most obvious between 2013 and 2014, and the market size growth rate after 2014 shows a downward trend. After the blockchain technology is integrated into the protection and management of digital music copyrights, it is predicted that the market size of digital music will continue to expand between 2020 and 2023; also, the changes in growth rate will be affected by multiple factors, including complex market environments.

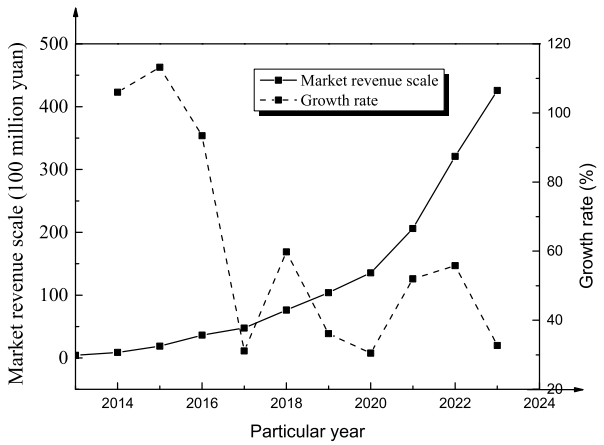

FIGURE 7. Changes in the scale and growth rate of the digital music market.

IV. DISCUSSION

The piano composition completed by a computer automatically is a challenging problem to evaluate its quality. The quality of piano automatic composition is analyzed and evaluated by using manual analysis evaluation and passage pauses. The analysis results show that the introduction of GRU network in the RNN model not only solves the problem of time dependence but also has good results in both manual evaluations and passage pause analysis.

As the Internet develops rapidly and the online creation becomes popular today, more and more musicians have become one of the online creators. With the continuous deepening of research on automatic computer composition and the enhancement of people's awareness of rights, many music practitioners begin to be aware of the protection of music copyright. Here, the blockchain technology is incorporated into the construction of a digital music management system, which is of great significance for promoting the increase of the stickiness of users and the strengthening of public copyright concepts and awareness. Besides, as for the application of blockchain technology in digital music copyright management, operations are easy to be implemented, the transaction efficiency is improved, and the integration of blockchain and copyright can better serve the copyright protection and management of digital music works. Compared with the traditional digital music copyright management and transaction, the integration of blockchain technology makes the copyright management of digital music have more obvious advantages in terms of ownership, use rights, and rights protection [23]. However, at the same time, because the research on blockchain technology in digital music copyright protection and management is still in the exploration stage, coupled with the current social background, there are still some problems in the application of blockchain technology. For example, from a technical perspective, there are technical barriers in the blockchain technology, and related technical measures still need to be developed. From a security perspective, the application of blockchain technology is a double-edged sword, and the relevant security index still cannot be completely determined and predicted. From the perspective of policy implementation, the relevant responsible departments have not paid enough attention to blockchain technology, and the promotion of related core technologies still has certain limitations. In addition, the lack of talent in the field of blockchain technology also limits the level of blockchain technology development. At the same time, it cannot be denied that blockchain technology plays a critical role in the connection between automatic computer music composition and copyright protection and management of digital music, which has broad application prospects in the music field.

V. CONCLUSION

Based on the excellent characteristics of deep learning methods and blockchain technology, the RNN model and GRU network based on deep learning are applied to the piano automatic computer composition neural network model, and the GRU-RNN model is proposed. After the blockchain technology is integrated into its copyright protection and management, it has been found that compared with other music composition generation methods, the GRU-RNN model has shown satisfactory effects in manual analysis and evaluation, as well as in the pause analysis of music passages. The application of digital music copyright protection and management has a positive effect on promoting the popularization of digital music and expanding the market size. However, due to the influence of experimental conditions, the selection of quality evaluation indicators for automatic composition music is not comprehensive enough. At the same time, the application of blockchain technology is in the exploration stage and has not yet matured. Therefore, the application of blockchain technology in the music field is also in the exploratory stage, which will be deepened in the future.

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