Virtual Reality Computer-Aided Design of Music Fountain based on Music Feature Recognition

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Abstract. Fountain is an important facility in modern garden art, engineering architecture and landscape appreciation. Ordinary fountain used to adjust the water valve, the water of the fountain with a fixed height, the height of the fountain can't be flexible changes, the music fountain is a kind of has a high ornamental value of landscape, in real life not only beautify the environment, more people brought happiness, is one of the more popular in recent years. Landscape architecture and music appreciation are combined with the product. In this paper, the fountain model matching each musical emotion mode is designed, and the fountain design is reflected by the three-dimensional animation simulation display of the music fountain. The system can design the music fountain performance program reflecting the music connotation according to the characteristics of different songs. Through the comprehensive use of computer animation, automatic control and other technologies, greatly improve the development efficiency of the music fountain performance program. In this way, the characteristics of different music songs are expressed in the form of music fountain, and through the recognition of music characteristics and intelligent control of the fountain, the music melody, water spray form, rhythm and emotion are combined together, water flow constantly changes with the rhythm of music, plus the rendering of lighting, especially charming. Which can save a lot of manpower, material resources and financial resources, reflecting the advanced technical level of music fountain design, greatly improving the efficiency of music fountain production.

Keywords: Computer aided design; virtual reality; music fountain; feature recognition
DOI: https://doi.org/10.14733/cadaps.2023.S1.162-173

1 INTRODUCTION

In recent years, with the rapid development of economy, people's living standards continue to improve, living environment, art edification, spiritual construction are constantly improved, especially the living environment and higher expectations for tourist attractions. At present, the waterscape has become an indispensable visual enjoyment in life, and the music fountain has become an attractive hot spot in many living communities and tourist areas. The Fountain of Music is a realistic man-made landscape that combines changes in water, light and music with its surroundings. Create a variety of styles, different styles of art styles, bring endless audio-visual enjoyment to people, music fountain will be beautiful music, colorful lights, clear and bright spectacular water jet interwoven together, to meet the needs of modern people close to nature, so the rapid rise and development of music fountain industry. In addition, the music fountain also has the function of space separation, beautifying the living environment and purifying the air. Combining water, music and light, it presents a beautiful, interesting and artistic experience. It is a highly ornamental water landscape, which organically integrates light, music, water and even movies, and produces a variety of water shapes with the change of music, which can bring people an audio-visual feast. At the same time, the music fountain can also increase the three-dimensional sense of space, beautify the surrounding environment and air purification.

The so-called music fountain refers to the use of various characteristics of music to control the fountain pump running combination and speed changes, as well as the combination of light changes of the fountain. A good musical fountain can instantly combine the visual perception of the changing water column with the listening experience of the music to create a perfect environmental artistic effect. At present, with the rapid development of computer software and hardware technology, the interactive application of new music fountain and computer is more and more extensive, and the music fountain is becoming more and more complex and more and more complete. Shu and Ma [1] mentioned that as an art form combining auditory art and visual art, the music fountain has received extensive attention. A fountain is a combination of water or other liquids that have a specific shape when sprayed under pressure. In general, fountain landscape can be divided into two categories: one is according to the local situation or according to the scene of the terrain structure, the natural landscape formed waterscape, such as wall spring, spring, fog spring, pipe flow, stream, waterfall, water curtain, water droplets, waves, whirlpools and so on; Another water feature that relies entirely on man-made landscapes is a fountain device.

At present, although many music fountains have been built at home and abroad, most of them have two shortcomings: firstly, the design of music fountain performance program needs the cooperation of music, stage designer, computer, self-control, fountain and other professional experts; Secondly, in order to understand the jet effect of the music fountain performance program, only on the hardware simulation experiment. In the past, the music fountain is still lacking in intelligent control. Xu et al. [2] mentioned that many fountains are program-controlled and need manual off-line pre-programming. This mode will cost a lot of manpower and material resources, and technicians can only deal with many contents of the music simply, and cannot make the fountain more diversified. There are also some intelligent music fountains on the market, but the music features that can be recognized are relatively single, which is not enough to reflect the connotation of music. This pattern of fountain performance is not rich enough to attract the audience. Music fountain system is a more complex system engineering, it involves more disciplines, including music, aesthetics, computer, graphics, optics, machinery, control and so on.

The purpose of this article belongs to the second category of the fountain, music fountain waterscape, it will through different music melody of pitch, intensity, drum rhythms and melodies and degree of the strength of the audio and so on music features into different information into the computer, the computer programmed through the implementation of music signal feature recognition, analyze and find out the characteristics and styles of the music, such as melody and beat. Then, according to the pre-prepared basic performance program library of water type and

combined with the analyzed music characteristics, output various switching and analog control signals to the executive mechanism to realize the fountain shape changing with the music. In this system, firstly, the basic characteristics of music are extracted, and then on this basis, the characteristics of musical form are analyzed and the whole music is divided into several sections, and the basic emotional colors expressed by each section of music are analyzed. The second step, according to the musical form and emotional characteristics, matches the corresponding basic music fountain performance program for each section, thus generating the initial music fountain performance program. The performance program can be simulated with three-dimensional animation, and can be modified through a friendly man-machine interface until satisfactory. The final performance program is automatically compiled, which can control the fountain to spray according to the designed action, and realize the synchronization of music and fountain.

2 MUSIC FEATURE RECOGNITION TECHNOLOGY AND VIRTUAL REALITY TECHNOLOGY

2.1 Music Feature Recognition Technology

Sound has four characteristics: pitch, length, intensity and pitch, which are related to the frequency and duration of sound body vibration respectively. Physical quantities such as amplitude and spectral distribution correspond to the three basic elements of a piece of music: melody, rhythm and harmony. At the same time, basic music theory includes notes, length, pitch, volume, tone, name, fundamental frequency, beat, rhythm and speed. Instruments can be divided into strings and pipes according to the way objects sound. Yang et al. [3] mentioned that Wind instruments are made by vibrating air in a tube, while string instruments are made by vibrating strings. Such as guitar is a string; Harmonica is a pipe. The melody of a piece of music is constantly changing, so the emotion of the music is constantly changing, sometimes intense, and sometimes quiet. The performance process of the musical fountain is also changed with the continuous change of musical emotions and the corresponding performance water type, which makes the fountain varied. In order to perfectly combine the water type of the music fountain with the emotion of the music section, it is necessary to divide the music section and identify the emotion, and then match the emotion section with the basic performance program library. The basic characteristics of pitch, tone strength and length cannot directly express the emotion of a piece. The emotion of a piece needs to be analyzed from the complex characteristics, which can correctly express the emotion, including the rhythm, performance speed and melody of music.

Music emotion pattern recognition can be identified by music elements with music elements identification, cannot be identified by music elements in the song database input song emotion words, directly used for emotional patterns. Panda et al. [4] mentioned that lighting and water emotion are divided into eight modes according to music emotion and built in the database. It is relatively simple to match by music emotion mode. Water emotion is modeled and combined with four water types in each mode. According to the eight emotional patterns of music, the corresponding relationship of musical emotion, light color and water type of musical fountain is summarized, namely the emotional waterscape pattern of musical fountain. The melodic variations in different musical genres is shown in Figure 1.

Music recognition methods are mainly based on short-term frequency domain analysis. Signal time domain analysis is to analyze and extract the time domain parameters of music signal. The short-term autocorrelation function is mainly used to estimate the fundamental frequency of musical notes. The short-term energy and the short-term zero crossing rate are used to detect music fragments. The short mean amplitude is used to identify the intensity of the note.

The analog output of music fountain mainly refers to frequency converter control. Ac induction motor has three speed control methods: variable speed regulation, differential regulation and frequency control. The use of frequency conversion speed regulation can not only realize step less speed regulation of the motor, but also adjust the relationship between voltage and frequency

according to the characteristics of the load. The motor can always operate in an efficient area and ensure good dynamic characteristics. Music signal recognition includes: Digital and preprocessing of music signal. Analysis of time and frequency domain of music signal. Specific steps include: music signal preprocessing, drum recognition, melody tone recognition and speed recognition. After extracting characteristic elements, they are applied to fountain control system.

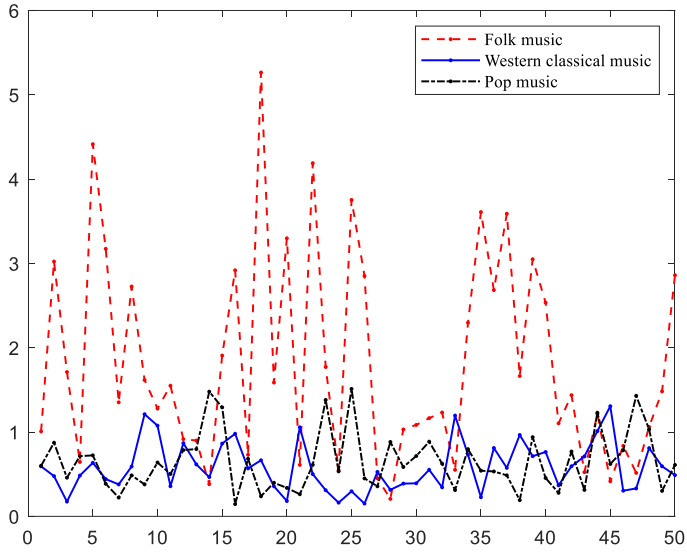

Figure 1: Melodic variations in different musical genres.

2.2 Virtual Reality Technology

Virtual reality simulation generated by computer technology to realize virtual environment, through the computer hardware technology and image processing technology, users can realize a through perception means such as sight, hearing, touch, smell perception to the virtual environment, users with special output and input devices, for tours in the virtual environment, a virtual environment for user feedback, In this way, people feel as if they are in the real environment. Ballantine [5] mentioned that the emergence of virtual reality enables people not only to feel things in the objective world through the virtual world, but also to break the limitation of time and space and feel the feelings that cannot be experienced in the real world. Virtual reality is essentially through the computer, to provide people with visual, auditory, tactile feelings and at the same time can truly and naturally feel the virtual world, greatly convenient for people to use, so as to reduce people's work burden, very high work efficiency.

Virtual reality technology is a comprehensive technology, which integrates computer graphics, sensor technology, interactive technology and network technology. The most basic requirement of virtual reality technology is to realize real-time interaction with users [6]. Therefore, a basic virtual reality system is mainly composed of computers, I/O devices, application software and databases. Virtual reality environment is a kind of environment that exists in the computer by constructing geometric model and physical model and needs some special equipment to feel. Such an environment can only be called a virtual reality environment if it can interact with users in real time and users have absolute autonomy. The basic features of virtual reality include:

(1) Interactivity: This is the main feature of virtual reality technology. In virtual reality, users do not have to watch and listen passively, but can control and even create thing.

(2) Immersion: With the aid of computer hardware and software, such as a head-mounted devices such as stereoscopic display, digital gloves or coat, let users fully immersed in the computer to build virtual simulation environment, users have the sense of reality, as it were, the feeling of the user and perceived resemblance and status in the real world, people immersed in the virtual environment and in the real-world experience, difficult to difference.

(3) Imagination: People immersed in the virtual world can rely on their own perception of the cognitive ability of all-round access to information, exert their subjective initiative, broaden its cognitive range, not only can be in a virtual world representation of what is real, and can also play to your imagination, construct the real world does not yet exist, seek new concepts and ideas.

(4) Multisensory: It refers to that in addition to the visual and auditory experience provided by the general virtual reality technology, it can also provide the experience of touch, smell and force, and even provides the experience of taste. The envisaged virtual reality technology can make people feel all the experience effects. However, in view of the lack of scientific and technological development level. At the present stage, virtual reality technology can only provide the public with the most basic perceptual experience, such as vision, hearing, touch and so on. Its perceptual range and accuracy cannot be compared with the real world.

3 SYSTEM STRUCTURE DESIGN

Since the musical form features reflect the overall structure of music, while the emotion of music reveals the connotation of music, the musical animation based on the two can not only be consistent with the overall structure of music, but also properly express the connotation of music, which is composed of four parts: firstly, some basic musical features are extracted directly from MIDI files, and on this basis, the musical form features are extracted, so as to divide the whole music into small sections. Secondly, identify the feelings expressed in each passage; Thirdly, select the physical model for the animation, based on experience to establish the basic performance program library based on the model, each of the basic performance program stored in the library can well represent a certain emotional color; Fourthly, the fuzzy expert system is used to match the musical emotion of each piece with the basic performance program, so as to automatically design the musical animation that can reflect the musical emotion [7].

(1) music pattern recognition: we choose MIDI file as input audio source, because a lot of basic music features (pitch, timbre, duration, etc.) can be gained directly, on this basis, we can be of melody, harmony, rhythm and complex characteristics is analyzed, so as to identify the buckling characteristics of music, and the entire piece of music is divided into some passages. Ferri et al. [8] mentioned that according to the music information including basic features and complex features, the music can be divided into several sections according to the structure of the music, and the emotional color of each section can be identified by fuzzy classifier.

(2) Music emotion recognition: we first classify music emotion according to the theory of music psychology, and then identify the emotion of each piece by a fuzzy classifier. In this part, the fuzzy expert system is used to match the music features with the jet action at two levels-segment matching. Paragraph matching refers to finding appropriate basic performance procedures for each paragraph according to emotional colors, that is, typical action sequences used to express a particular emotion. Note matching is the arrangement of a specific jet action for a specific note. The matching process of these two levels is the final design process of the music fountain performance program, which records all the states of the music fountain dancing with music.

(3) Basic performance library: The basic performance library stores a large number of basic performance programs, that is, performance action sequences. These basic performance procedures are designed by the designer according to the characteristics of the animation model, and each action sequence can well express a certain kind of specific emotion. Since the number of basic performance programs will directly affect the effect of CAD system, we specially designed an expansion mechanism for it, that is, the user can input the new basic performance program into

the basic performance program library through a very friendly man-machine interface, or modify the existing basic performance program arbitrarily. The parameters of animation are all designed in accordance with the actual fountain feast test device, and the simulation of the actual spray effect can be realized through animation.

(4) Matching of music and jet action: this part is completed by matching music with basic performance program through fuzzy expert system. This matching consists of two levels - segment matching and note matching. Paragraph matching refers to finding the appropriate basic performance procedure for each paragraph according to the emotion, while note matching refers to arranging specific performance actions for specific notes. In order to enable users to modify the performance program without knowing the internal code, the author developed a very good man-machine interface. The interface can not only realize single-point modification, multi-point modification, but also select another set of performance actions for the whole piece of music. The system implementation function flow chart is shown in Figure 2.

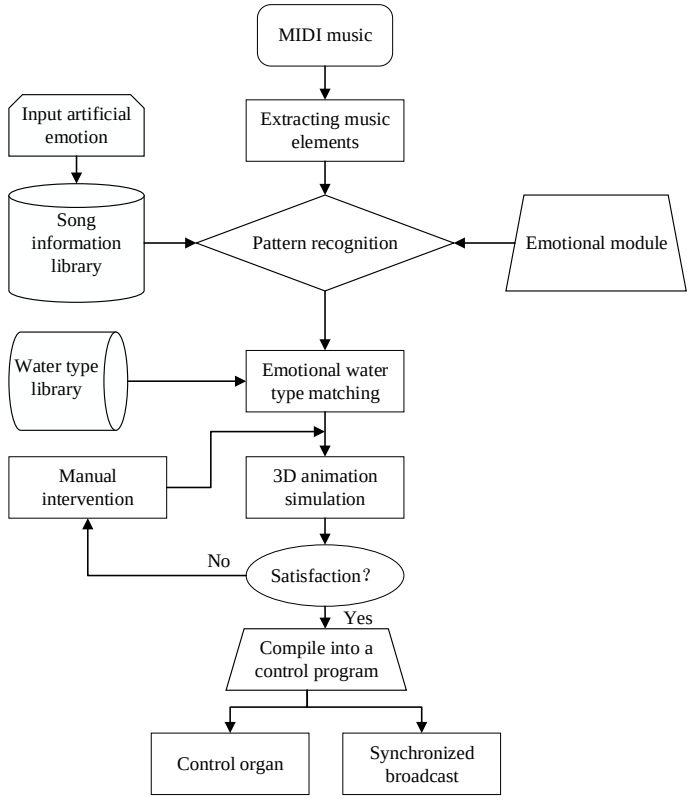

Figure 2: System implementation function flow chart.

By studying the characteristics of music, music emotion recognition can be roughly divided into three processes. The first step is to extract the basic characteristics of music, the second part is to separate out the complex characteristics of music and divide the music into several sections, and the third part is to identify the emotional color expressed by the section according to the characteristics of the section. Then, according to the emotional color of each piece, find the corresponding music fountain water performance scheme for each piece, and then generate the fountain performance program. The fountain system then performs the performance. To achieve

synchronous control, the music fountain system divides the music signal into two parts. After some signals are preprocessed, they are sent to the computer to extract the features of the music through their respective algorithms, and then the emotion identification of the music segments is carried out through the features. Finally, the corresponding music fountain water type is matched for the segments to form the fountain performance [9]. Another part of the signal is sent to the mixer after filtering processing, then delayed processing, and then sent to the power amplifier equipment for power amplification, and finally sent to the sound system for playback.

Particle system is widely used in fluid modeling, and has been proved to be an effective method to simulate amorphous objects. Its development has been relatively mature, and there are two main types: state independent particle system and state dependent particle system. In this paper, the state independent particle system is adopted. According to the particle system modeling method, the main fountain particle attributes can be represented by three-dimensional vectors [10]. The music fountain simulation process is shown in Figure 3.

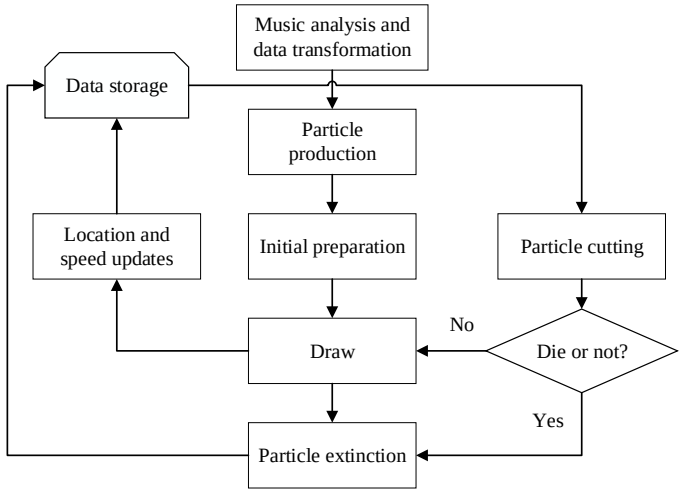

Figure 3: Music fountain simulation process.

4 ANALYSIS OF EXPERIMENTAL RESULTS

In order to verify the simulation method of music fountain described in this paper, a small channeling music fountain is selected as the physical model of music animation. The fountain consists of 13 sprinkler heads and four sets of colored lights. The 13 nozzles were divided into 4 groups, 1~6 nozzles belonged to the first group, 7~9 nozzles belonged to the second group, 10~12 nozzles belonged to the third group, 13 nozzles belonged to the fourth group. The nozzles in the first group can swing tangentially and radially at the same time, the nozzles in the second and third groups can swing left and right, and the nozzles in the fourth group can't swing. At the same time, each set of nozzle on the jet height can have four levels of change in addition, this model is equipped with four groups lights, each group is composed of three different colors of light bulbs, so you can create a colorful lighting effects, making fountain form rich and colorful, has stronger expression to the music, give a person the sense of pleasure.

When there are few basic performing programs in the basic performing program library, the fountain's posture changes have a lot of repetition, but when the basic performing program library is expanded, the fountain's movement design is more satisfactory. Take 'The Blue Danube' for example, the prelude part is a simple swing under the blue light, and the small waltzing corresponding to the joyful, lyrical, or passionate section of the jet movement, and the end is all the water spray scene. When a similar melody appears, the movement of the jet is exactly the

same. If it appears at different speeds, the speed of the jet will change accordingly, basically achieving the same visual and auditory feelings. The time domain waveform of music is shown in Figure 4.

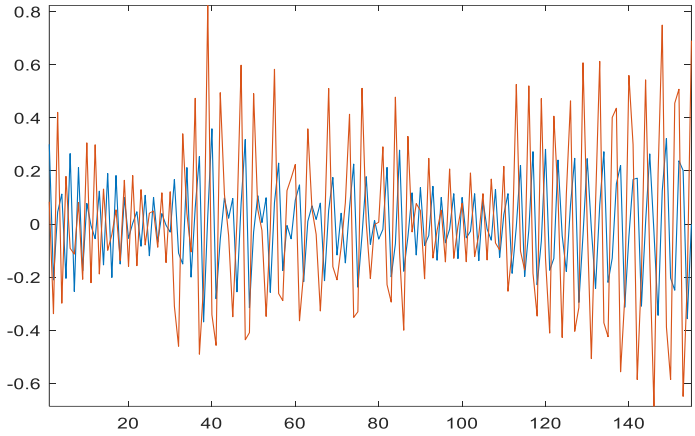

Figure 4: Time domain waveform of music.

Music fountain is a magic color sound control, modern technology and art integration. The movements of various mechanisms of modern fountain are complex and varied, changing rapidly, but also need to be synchronized with music, so the computer control system must complete the process of automatic selection of music fountain, synchronous demonstration, control and storage of music and other information data processing and monitoring operation. According to the dimension of segment feature vector, the number of neurons in the input layer of the network is determined. The network output layer is the emotional type of the musical passage. This paper adopts a simplified emotional model, so the musical passage after the neural network is divided into four emotions: intense, cheerful, calm and sad. Although the performance program designed automatically is not very satisfactory, but because we make the human-computer interaction interface is very friendly, the modification of animation is very convenient, compared with the traditional hand animation, greatly improve the production efficiency of the music fountain. The diagram of the distribution of musical structures is shown in Figure 5.

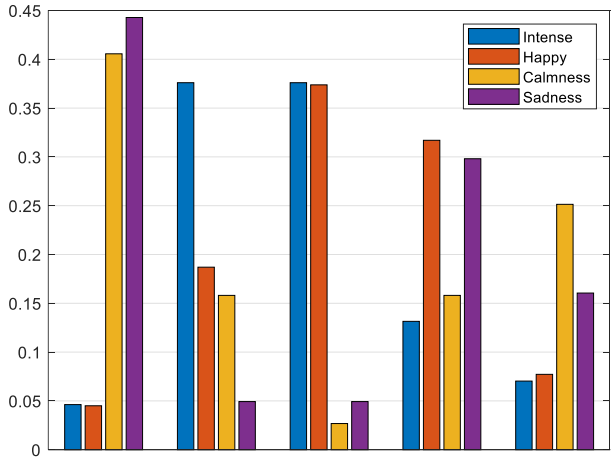

Figure 5: Diagram of the distribution of musical structures.

In this paper, the constructed neural network emotion recognizer is used to identify the emotion of the passage, as shown in the figure 1, 2, 3 and 4 in the figure respectively represent the four emotions: 1 represents happiness, 2 represents calmness, 3 represents sadness, and 4 represents intensity. Red represents the prediction segment category, blue represents the actual segment category, where the ordinate represents the emotional category and the abscissa represents the segment. It can be seen from the figure that most of the emotion recognition is accurate, but there are some errors in the emotion recognition of individual segments. The classification error diagram is shown in the figure. The value of the classification error is composed of the difference between the actual value and the predicted value, where the ordinate represents the difference and the abscissa represents the segment. According to the number of correctly classified four emotions, there are 35 segments of sad emotion, 49 segments of calm emotion, 42 segments of cheerful emotion and 48 segments of intense emotion. Finally, the accuracy of emotion recognition is obtained through calculation. According to the satisfactory results of 3D visual simulation of music fountain, the control code information database is established to control lighting, water pump, sprinkler head, swing machine and frequency converter. The classification simulation diagram of predicted and actual segment types is shown in Figure 6.

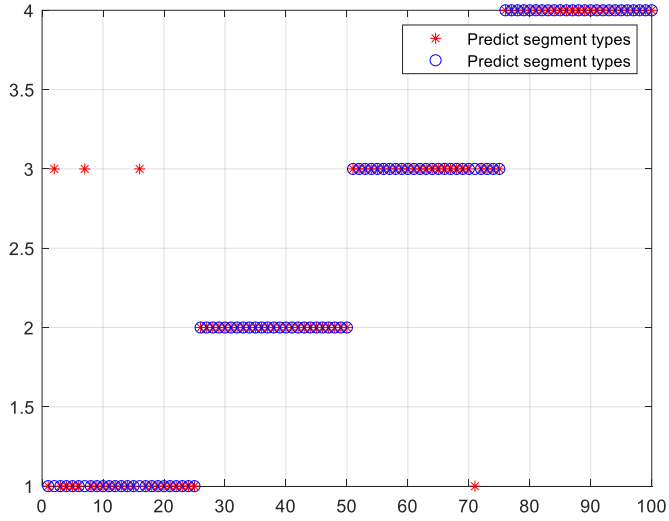

Figure 6: Classification simulation diagram of predicted and actual segment types.

The prelude is a simple swing under the blue light, and the small waltzing is corresponding to the joyful, lyrical, or passionate jet movement, and the end is all the water jet scene. When a similar melody is played, the jet action is exactly the same; if enough different speeds appear, the jet speed will change accordingly, basically achieving the visual and auditory experience of the same. With a few modifications, the performance program was performed synchronously with the music on the music fountain experimental device. According to the result of BP neural network emotion recognizer, compared with other algorithm emotion recognition results, the emotion recognition of the passage has higher accuracy and can accurately identify the emotion category of the passage, which proves that the algorithm can accurately identify the emotion of the passage, providing a basis for the matching of the passage and the fountain water performance. The simulation diagram of BP network classification error is shown in Figure 7.

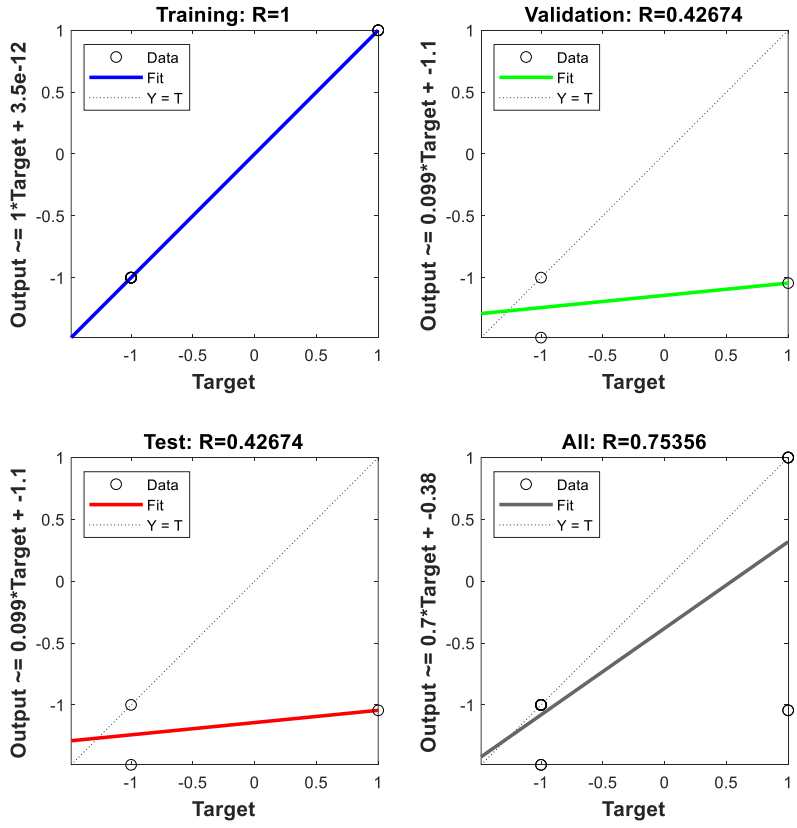

Figure 7: Simulation diagram of BP network classification error.

5 CONCLUSION

With the rapid development of computer software and hardware technology and modern control technology, new music fountains designed on the basis of modern high technology emerge one after another. At the same time, the types and styles of musical fountains are blooming. In today's era, computer automatic recognition signal, the intelligent control of music fountain has become the main direction of the fountain in the future. In this paper, the basic knowledge of music is analyzed, and the basic characteristics of music are studied according to the musical characteristics and physical characteristics of music. Through the detailed analysis and elaboration of music, music recognition and the basic principle of the music fountain control system, and then more scientific and close research on the music fountain. The integration of modern fountain engineering and computer technology has laid a solid foundation for the birth of high-end musical fountain. Generation of music fountain through a number of high and new technologies, the fountain's landscape effect is unique, bring incomparable pleasure to people, but also for people's life with fun, but also for the future development of music fountain has laid a foundation.

First of all, through the analysis of the basic nature and organizational structure of music, extract the characteristics of notes, on the basis of the extraction of notes, pitch, intensity, length and other features. The algorithm is used to extract music bar line and feature vector of music bar. Then, according to the cosine of the Angle between vectors, the similarity of adjacent music bars is judged, the music bars with similar feature vectors are connected, and the music is divided into independent emotional segments.

Then, through the division of musical passages, the seven-dimensional emotional feature vectors of musical passages are extracted, which include three degrees, minor three, playing speed, beat, the intensity of change of rhythm, the average value of intensity, and the direction of melody. Using the emotion model, the passage was divided into four emotions (intense, sad, calm and happy). The BP neural network is used as the emotion recognizer to find the mapping relationship between music feature space and emotion space, classify the emotion of music segment, and identify the emotion type of music segment.

Finally, identify the emotion of the segment, match the basic program library of the music fountain, and design the structure and model of the basic program controller. The paper analyzes the emotional expression of lighting color and water type emotion expression, and designs the implementation plan of music fountain.

Music fountain system engineering is quite complex, and it needs professionals from multiple disciplines to design, including music, automation and machinery, and the research content is also relatively extensive. Although the article has carried on a lot of analysis to the music fountain, but there is still a lot of knowledge about the music fountain worth studying. The following are the main questions that can be studied in the future.

1. Waveform music files are very complicated, and there are many feature vectors to express music. For different music types, the feature expression of music is also inconsistent. In order to make music feature vector better express music emotion, it is necessary for researchers to have a certain understanding of music, and optimize the algorithm to extract more effective features to express music. The musical characteristics studied in this paper are still in the initial stage, and there are still huge research values waiting for researchers to participate in.

2. Real-time audio-controlled music fountains have a lag problem. In order to solve this problem, this paper adopts the method of hardware delay. This music lag time is the sum of the extraction time of music features and the mechanical inertia time. It can only realize the synchronization of fountain and music to a certain extent, but there are still many defects in the practical application process. The effect may vary depending on the music. Researchers can also use software delay to synchronize the music with the fountain by using predictive algorithms to predict the time of the delay.

3. Segment emotion recognition technology is a relatively frontier research field, in order to make researchers more convenient to analyze the performance of algorithms. Researchers can try to set up a standard protocol and music test database.

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REFERENCES

[1] Shu, S.; Ma, H.: Restorative effects of classroom soundscapes on children's cognitive performance, International Journal of Environmental Research and Public Health, 16(2), 2019, 2-15. https://sci-hub.et-fine.com/10.3390/ijerph16020293

[2] Xu, L.; Wen, X.; Qian, X.-Y.: Effects of individual factors on perceived emotion and felt emotion of music: Based on machine learning methods, Psychology of Music, 49(5), 2020, 1069-1087. https://sci-hub.et-fine.com/10.1177/0305735620928422

[3] Yang, X.-Y.; Dong, Y.-Z.; Li, J.: Review of data features-based music emotion recognition methods, Multimedia Systems, 24(4), 2018, 365-389. https://sci-hub.et-fine.com/10.1007/s00530-017-0559-4

[4] Panda, R.; Malheiro, R.; Paiva, R.-P.: Novel audio features for music emotion recognition, IEEE Transactions on Affective Computing, 11(4), 2020, 614-626. https://sci-hub.et-fine.com/ 10.1109/taffc.2018.2820691

[5] Ballantine, C.: Against populism: music, classification, genre, Twentieth-Century Music, 17(2), 2020, 247-267. https://sci-hub.et-fine.com/10.1017/s1478572220000043
[6] Abboud, R.; Tekli, J.: Integration of nonparametric fuzzy classification with an evolutionary-developmental framework to perform music sentiment-based analysis and composition, Soft Computing, 24(13), 2020, 9875-9925. https://sci-hub.et-fine.com/10.1007/s00500-019-04503-4
[7] Lee, Y.-S.; Kim, S.-Y.; Moon, H.-S.: A comparative study of the accuracy of dental cad programs in designing a fixed partial denture, Journal of Prosthodontics-Implant Esthetic and Reconstructive Dentistry, 31(3), 2022, 215-220. https://sci-hub.et-fine.com/10.1111/jopr.13406
[8] Ferri, A.; Varazzani, A.; Baj, A.: A multicenter survey on computer-aided design and computer-aided manufacturing mandibular reconstruction from Italian community, Microsurgery, 39(7), 2019, 673-674. https://sci-hub.et-fine.com/10.1002/micr.30505
[9] Small, C.; Laycock, H.: Are we near to making virtual reality the new reality in pain medicine, Anaesthesia, 76(5), 2021, 590-593. https://sci-hub.et-fine.com/10.1111/anae.15252
[10] Allcoat, D.; Hatchard, T.; Muhlenen, A.: Education in the digital age: learning experience in virtual and mixed realities, Journal of Educational Computing Research, 59(5), 2021, 795-816. https://sci-hub.et-fine.com/10.1177/0735633120985120