Research Article

Design of Tone Recognition System for Pipa Strings Based on Wireless Sensors

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Pipa has been widely used as a wooden musical instrument as early as the Han period. It mainly relies on human fingers to pluck the strings to make sounds. The timbre of the pipa also has a very strong national characteristic. Understanding the meaning of words, phrases, and sentences requires tone recognition. For tone identification, the fundamental frequency conveys the most unique information. This paper summarizes the influence of the pipa’s characteristics, technology and skills of the player, and the player’s factors on the timbre of the pipa performance. In addition, given the problems of low accuracy and high data packet loss rate in the existing pipa playing tone recognition methods, this paper proposes a pipa string playing tone recognition algorithm based on wireless sensors. According to the sensor stage and weight-corresponding characteristics, on the premise of minimizing the total mean square error, the optimal weight corresponding to the sensor measurement value is found according to the adaptive mode. The unbiased estimated value of the measured value of each node is obtained through iterative calculation. The Euclidean distance between the measured value and the estimated value of each sensor obtained by the normalization process is used as the adaptive weighted recognition weight. It completes the conversion of the adaptive weighted recognition algorithm structure and the binary recognition result. The experimental results show that the proposed method has good tonal recognition accuracy in the pipa playing environment.

1. Introduction

The Chinese pipa is a four-string plucked lute that originated in West and Central Asia and made its debut in China during the Northern Wei period (386–534). It introduced not just a new sound but also new repertoires and musical theories, as it traveled through historic trade routes. Because of pipa’s sound vast spectrum, the pitch range is crisp and strong, the middle is bright and delicate, and the bass range is mellow and lyrical [1]. The audience is attracted to pipa performances because of its rich and varied timbre expression that occurs during the performance process. PIPA has been around in China for well over 2,000 years. Its complex and vibrant timbre has contributed to the particular attractiveness of pipa music art, which can be heard around the world [2, 3]. As a solo instrument, the pipa is capable of creating “a piece of its own” throughout the playing process. It radiates a distinct musical instrument appeal and can be employed as a background soundtrack for diverse performances [4]. It differs from contemporary pipa instruments in its design and construction. Unlike the ancient pipa, which is played predominantly with the horizontal bubble and strings plucking, the modern pipa is predominantly held vertically and played with fingers. It indicates that they are similar in terms of playing techniques and abilities. However, there are some distinctions [5, 6]. Traditional pipa can only play classical music, but modern pipa can also perform popular songs from around the world, including Western music. The pipa can be regarded as one of the various playing instruments used in the production of effect and expression among other things. A musical instrument that performs admirably in all elements of its design and construction. For example, in the process of playing “House of Flying Daggers,” with the flexible use of the pipa, one can use “twisted strings,” “sweeps,” “sha xian,” and “pushing doubles” in addition to the standard pipa technique. It has the ability to successfully recreate the tight atmosphere of a fierce battlefield, allowing the listener to experience the
intense battle on the battlefield in his or her own imagination. The enhancement of pipa music performance cannot be separated from the development of performance skills and the expression of positive emotions. When expressive techniques are employed to create a unique performance impact, they function in tandem. To put it another way, the employment of pipa performance skills and emotional expression methods can help represent more accurately the true feelings contained within the music being performed. The vivid expression and complete display of the charm of music can provide the listeners with a flawless experience and sensation that is more conducive to stimulating their emotional resonance. It also significantly boosts the overall effect of the pipa performance [7–9].

Identification of the tones of pipa strings can assist pipa players to prepare and regulating the strength, accuracy, and speed of their strumming [10, 11]. It allows them to progress more quickly in their performance [12]. Traditionally, video recording has been used to determine the tones of pipa strings. This involves filming the pipa players doing the entire process and then having professional pipa players carefully examine the video to find any flaws in the sound [13–15]. Although this method is time-consuming and labor-intensive, it does not accurately capture the flaws in the tone of the pipa strings [14, 15]. This was a common problem with traditional methods. There was a need to introduce an effective mechanism for distinguishing the tones of pipa strings [16–18]. Musical instrument tone identification is a topic that has gotten little attention in the United States and abroad. Only equipment and humidity are the subjects of many studies in the industry [19–21]. For example, some researchers are developing a real-time environmental monitoring system for greenhouses that integrates mobile terminals and WIFI wireless communication to monitor parameters such as soil moisture, light intensity, air temperature, and humidity in the greenhouse [22]. They are using sensors and single-chip microcomputers to collect environmental indicators in the greenhouse [23–29]. Users can access real-time greenhouse environmental information using a mobile application monitoring interface. This delivers the index data that is now being measured to the mobile client. Several researchers have developed a temperature and humidity monitoring system based on wireless sensor networks, employing the MSP430 as a development platform to build four parts: the data transmission circuit, the sensor data acquisition circuit, the MCU minimum system circuit, and the host computer monitoring platform. The system collects temperature and humidity information using the ZigBee protocol sensor network, and the gateway, whose core is an MSP430, is used to transmit the information [31].

Based on the benefits of the methodologies discussed above and the usage of wireless sensors, a wireless sensor-based tone detection system for pipa strings is being researched. Air temperature and humidity components are efficiently detected in the redundant information supplied by a large number of nodes using the adaptive weighted identification algorithm. It results in the highest level of consistency in reliability. This section of the software includes a graphical user interface to fulfill the visual requirements of the user and then eventually accomplishes the tone recognition for the pipa string playing system.

The rest of the research paper is organized as follows; Section 2 will explain the tone and timbre of pipa that plays a vital role in influencing its overall performance. Section 3 elucidates the tone recognition algorithm for pipa playing. Finally, Sections 4 and 5 put in words the results extracted and the concluding remarks.

2. The Influencing Factors of the Tone and Timbre of Pipa Playing

In this section of the research paper, the materials used in pipa will be explained. It will be followed by the player’s techniques and personal performance. This will give us an overall idea of all the factors that influence the tone and timbre of pipa playing.

2.1. Materials Used in Pipa. The pipa is primarily constructed of wood, with the backplate serving as the most important component of the instrument. The timbre produced by the pipa is significantly influenced by the backplate. The acoustic qualities of the materials used in the construction of an instrument are intimately related to the sound produced by the instrument. As a result, the majority of trees with higher hardness are picked when selecting the back of the pipa. A higher level of hardness results in a brighter and more distinct tone that may match the requirements of various styles of music, as well as a brilliant and solid resonance of the entire pipa during the performance.

The raw materials are generally classified into four categories: high, medium, low, and secondary. The back panel is crafted from red sandalwood. It is considered to be of great quality in this region. Its high grain density and strong wood enduranc result in a clear and introverted sound that is crisp and incisive. It also has a curling reverberation when the pipa is built of it. It is the most suitable option for creating pipa. If the rear panel is made of mahogany, the pipa is regarded to be of midrange quality. Its robust tone, lasting, and clear sound distinguish the pipa constructed of mahogany from other types of pipas. It is also the most suitable material for the production of the pipa. Its structure is identical to that of mahogany, and the tone is likewise superior.

As white wood is softwood, the back panel made of white wood is regarded as second-grade because the tone is low and there are numerous disadvantages to utilizing it. When selecting the wood for the pipa’s back, be sure to use wood that has been exposed to natural wind. Longer wood air-dry produces a better production effect and beautiful sound. The pipa’s sound is also affected by the quality of its front panel. It is made of wood or plastic. Lankao sycamore planks are typically used as the front panel, although a well-grown Lankao sycamore tree only contains two of the best boards, and the paulownia wood is loose. Furthermore, due to high-water absorption, it is necessary to maintain a consistent level of humidity; otherwise, the sound quality of the pipa will be compromised. In addition, the panel’s wood grain must be straight, and the joints should be examined for gaps.
The strings of pipa were previously made of silk. The instrument was referred to as having “silk strings” before 1950. It produces a low sound with a clean timbre and needs less effort to push and pull than nylon strings. The drawback is that the service life is quite short. When playing ancient songs, on the other hand, it is simple to comprehend their allure and fully exhibit the feelings elicited by their works. As civilization has developed and progressed, the strings of pipa have also evolved and improved. Steel strings are now emerging that not only produce louder sounds but also last longer. They allow it to fulfill the demands of contemporary and classic music. As a result of the comparatively high tension of the steel strings, the ability of the player to maintain control over the instrument is demanded to be greater. Later, it was discovered that the tone of nylon strings was softer than steel strings, and the musicians were also exceptionally skilled at performing traditional repertoire. As the power is insufficient and the service life is short, silver nylon strings, which generate a clean, transparent tone that will not corrode, are now the newest additions to the collection.

Pipa nails may be divided into four groups based on their material composition: plastic, tortoiseshell, celluloid, and nylon. Plastic nails are particularly problematic because they have a low timbre and are prone to breaking. Tortoiseshell has a harsh timbre and is nonelastic. It also lacks the accompanying softness of other materials. Celluloid has a gentle tone, yet it is expensive to produce and maintain. Nylon nails are by far the most effective. The nails have a soft and round appearance, and they have a high level of wear resistance. The lute’s tone is heavily impacted by the instrument’s strings and fingernails.

2.2. Player Techniques. There has been a tradition of pipa for more than 2,000 years. The performance techniques are complicated and diverse, with the performers learning their skills through a period of years of self-exploration. Picking, fingering, sweeping, and other similar techniques are used to play the pipa with the right hand. Pressing, striking, overtones, twisting strings, and chords are some of the techniques used by the left hand while playing. Furthermore, the angle, position, and depth at which the musician makes contact with the strings have a significant impact on the timbre. An excellent example would be a right angle of 90° between the player’s nails and the pipa panel. This results in a weak resonance effect, which creates a sharp and harsh sound. The utilization of this condition is limited to situations in which special effects are necessary. When the player’s nails are broken, the pipa panel gradually shifts from 0 to 90 degrees when the pipa panel rotates. This transformation process has a significant impact on the timbre. It will shift from graceful and gentle to harsh and mellow as a result of this transformation. The sound is produced when the player’s fingernails and the pipa panel are at a 45° angle to one another. In addition to being sweet and pleasant, the timbre is also extremely robust and bright. Normally, the player will make the nails and the pipa panel at a 45-degree angle to each other. The timbre can also be affected by the nails to a certain extent. The positive front is powerful, and the timbre is audible and understandable. While the upper front is more mellow and rich, the lower front is more delicate and moisturizing, and the side is more delicate and moisturizing. The depth of the strings is also taken into consideration by the player. Putting the fingernails on the strings will result in a low volume of plucking. It can be readily raised by increasing the frequency of plucking. If the player’s fingernails are deeply embedded in the strings, his or her response speed will be reduced to a certain degree of sensitivity. Thus, the technique should only be adopted in a specific situation. When there is no special requirement, the contact point of the first string is usually in the 1/2 parts of the hand to the last fret, and the other is depending on the thickness factor. It is also shown in the illustration. When one is playing, the material will lose its flexibility and become fairly stiff.

The tension in the timbre increases is directly proportional to the strength of the force used to pluck the pipa. Generally speaking, if the plucking force is weak, the timbre will be softer. For example, in “House of Flying Daggers,” when the pipa is utilized to perform the song, the playing strength must be increased to convey the grandeur of the piece, and the “sweeping,” “flicking,” or the faster frequency “sweeping” can be used to do this. Particularly in the finale of “House of Flying Daggers,” that is, the “Battle of Jiuli Mountain,” the Serpa’s strength talents can effectively simulate the noisy scenario. This can have a significant impact on the appeal and influence of the audience. If one is going to play “Fu,” it is important to adjust the plucking strength suitably and portray the wrath that exists in the heart of the pipa girl as well as the melancholy sigh of fate in the music in a polite manner. “Su” is music that can be recited with a lot of freedom. Throughout the song, the level of the music changes from powerful to weak. This board was used when the lute girl described the beauty of the music and dance scenes that took place in the palace. It was a rather poetic slow-medium board. It will unintentionally express emotional responses.

A more in-depth analysis of the relationship between strength and timbre can be found in the description of influencers. Among the most notable characteristics are that loud tones are not harsh, weak tones are not empty, and the yin and yang, soft and rough, are organically blended. Examples include the fact that in Taiji culture, rigidity is softened by gentleness, and tenderness defeats rigidity. Consider the song “Xu Lai,” in which the left hand of the player continually plays the notes “Chuo” and “Note” for a long period. It creates a beautiful and pleasant melody. There is a sense of reality in the virtual, and the music flows elegantly. Aside from that, the right hand is used to play the middle syllable of the phrase. Songs with a strong sense of antiquity appear out of nowhere. Another example is the guzheng, which is the most appropriate musical instrument for the song “High Mountains and Flowing Water” (High Mountains and Flowing Water). When compared to its counterpart, the guzheng, the pipa has less resonance as well as less stringing and fretting than the guzheng, for starters. It is also vital to emulate the timbre of the guzheng when playing the instrument. Pipa players must fully employ their abilities in order to achieve a feeling of yin and yang balance, reasonable hardness and softness, and a sense of reality in the virtual environment.
Pipa possesses a wide range of abilities when it comes to performance, such as "Little Sisters of Heroes of the Prairie," a piece of music that will be used to more than 20 different types of abilities during the performance. There are a total of four portions to this work. In the first paragraph, the sisters’ employment of “Tang” and “Double Tumbling” for grazing on the broad prairie, respectively, is described. The character features of the two sisters are powerfully expressed and demonstrated. After the first paragraph portrays the cheerful and comfortable setting while grazing, the second paragraph describes the brave battle against the blizzard. Using the method of “collision,” the sound of a snowstorm on the grassland is powerfully conveyed. It also clearly demonstrates that the two sisters are protecting the flock, which is trying to survive in the blizzard. The third paragraph describes the story of the party’s sunshine in the heart. Using the abilities of "four-fingered long wheel" and "pick the string," relaxing and tenderly transporting the two sisters to the country. In this song, which conveys the most honest feelings for the party, as well as its heartfelt love and welcome to the small characters, the melodies are succinct and clear. The fourth paragraph is mostly on the abundance of crimson flowers that may be seen all around the homeland. The example above clearly demonstrates that the expression of different contents in a pipa performance will be expressed by different approaches or by touching the strings in different ways.

A total of 4 strings can be found in pipa. When the musician’s right hand makes contact with the strings, the touch location of each string varies, as does the sound emitted by each string. Putting the touching string in a lower position will produce a clearer, more vibrant audio signal. If the pitch is raised, the sound will be hollow. The sound produced by plucking the inner strings is more mellow, while the sound produced by plucking the outer strings is sharper. As a general rule, the music will have its set touch location; it is only while playing a specific tone that the touch position will be changed. When performing the "wheel" in "Moon’s High," the music specifies that the fingers should be moved widely. The touchpoint should be in the middle of the second and third strings, then move slightly in the direction of the third string, and the density of the wheel's fingers should be slightly looser than when performing the "wheel".

2.3. Personal Factor. When presenting music composed by an author to an audience, they must be able to enjoy and experience the music to its fullest potential. According to some, the performer serves as an intermediate narrator of music, which is a critical role. If a performer has a great deal of playing and performing experience, his understanding ability will be excellent, and his expression ability and expressive skill will be above average. The performer is the first appreciator of a musical work whether he can fully comprehend the artistic conception or emotion that the author wishes to express. It also has a direct and significant impact on the emotional conception that the subsequent appreciator can comprehend. Hence, the performer bears a great deal of responsibility. In conclusion, it can be seen that good work requires the performer to continue to dig deeper and analyze it comprehensively in terms of the historical context, social situation, and musical trend at the time of the author’s creation, as well as the characteristics of the author’s arrangement personal experience. In this way, the scene that the author wishes to express and describe will finally add to the performer’s understanding of the music and the sincerest emotion. When the emotional tone of the piece is represented through sound, the timbre of each note is flawless.

3. Tone Recognition Algorithm for Pipa Playing

The functional structure of the wireless sensor network system used to identify the tones of the pipa strings is primarily divided into six areas. They are the core control area, the network communication area, the data acquisition area, the data transmission area, the debugging interface area, and the power supply area. The core control area is further divided into two parts; the network communication area and the data acquisition area. The following are the particular contents of the document.

(i) First, the most important functions of the core control area are to control all of the hardware nodes, coordinate the functioning of each area, and analyze and process data from each area thoroughly.

(ii) Second, structured sensor networks, network node management and control, wireless data communication, and protocol stack-related hardware device control are all responsibilities of the network communication area, which is divided into two categories.

(iii) Third, the data collection region is the only section of the terminal node that has the role of collecting and preprocessing the string vibration amplitude. It is also the most expensive.

(iv) Fourth is the data transmission area. It is an exclusive portion of the coordinator and whose duty it is to transmit coordinator data to the host computer program.

(v) Last is the power supply area. Each device in the identification system has a unique power supply mode. The coordinator and the router are controlled by the external power supply mode, while the interrupting node is controlled by the battery power supply mode.

The structure is shown in Figure 1.

The sensor measurement data \( z(i) \) is as follows:

\[
z(i) = d(i) + e(i),
\]  

where \( d(i) \) represents the initial data, the noise data is represented by \( e(i) \), and the two data sets are superimposed on each other to form the sensor measurements. Assuming that the noise contained in each sensor has no correlation, has a standard deviation of \( s \), and has a mean of zero, the sensor measurement data is divided into two categories by the initial value. Because the effect of sensor noise is random,
set $e(i)$ is the noise interference of each type of data for the convenience of calculation, and the two types of data are described by the following formulas, respectively:

$$z_1(i) = d_1(i) + e(i),$$
$$z_2(i) = d_2(i) + e(i).$$

The mean values of $z_1(i)$ and $z_2(i)$ are as follows:

$$E\{z_1(i)\} = E\{d_1(i) + e(i)\} = E\{d_1(i)\},$$
$$E\{z_2(i)\} = E\{d_2(i) + e(i)\} = E\{d_2(i)\}.$$

It is clear from the above calculation that the average measurement value tends to be closer to the true value as the number of iterations grows. The best-unbiased estimate value is extremely resistant to noise. The following is a description of the specific procedure that the iterative algorithm goes through. It allows the predicted value to be used.

First of all, select any initial unbiased estimated value $T_0 = \{T^k| k = 0\}$, and use the following formula to solve

$$T_0 = \frac{Z_{\text{max}} + Z_{\text{min}}}{2}.$$

Then, according to the estimated value $T^k$, the sensor measurement data is divided into two categories: $R_1$ and $R_2$, and the following conditional expressions are satisfied:

$$R_1 = \left\{ d(n) \mid d(n) \geq T^k \right\},$$
$$R_2 = \left\{ d(n) \mid d(n) < T^k \right\}.$$

Third, the mean values of $R_1$ and $R_2$ are as follows:

$$Z_1 = \frac{\sum_{d(i)\leq T^k} d(i) \times N(i)}{\sum_{d(i)\leq T^k} N(i)},$$
$$Z_2 = \frac{\sum_{d(i)> T^k} d(i) \times N(i)}{\sum_{d(i)> T^k} N(i)}.$$

The vast majority of the components of a wireless sensor network system are huge sensor nodes. They work together to gather data, monitor targets, and sense environmental information in a coordinated fashion. Recognize the inflections made by the pipa strings when they are played back. Each sensor has a varied level of accuracy, and it is difficult to ensure that the reliability is uniform across the board. An adaptive search on the relevant weight can be performed based on the measured value of the sensor, resulting in a recognition that is close to ideal in terms of precision. As a result, an adaptive weighted recognition method is devised to do this. Figure 2 depicts the framework for the project.

Taking into consideration both the sensor stage and the weight-corresponding feature, under the premise of RMSE minimization, the optimal weight corresponding to the sensor measurement value is determined in accordance to the adaptive mode. In this way, the recognition result of the pipa string playing tone is obtained.
The number of known sensors is \( n \), and \( \sigma_1^2, \sigma_2^2, \cdots, \sigma_n^2 \) is the variance between sensors, \( x_1, x_2, \cdots, x_n \) are the measured values of each sensor that are independent of each other. After introducing the weighting factors of each sensor \( w_1, w_2, \cdots, w_n \). The processed weighting factor \( w_i \) and identification value \( u_n \) are obtained, and the constraints of the two indicators are as follows:

\[
\hat{x} = \sum_{i=1}^{n} w_i x_i. \tag{12}
\]

Then

\[
\sigma^2 = E \left[ \sum_{i=1}^{n} w_i^2 (x - x_i)^2 + 2 \sum_{i=1, j=1, i \neq j}^{n} w_i w_j (x - x_i) (x - x_j) \right] = \sum_{i=1}^{n} w_i^2 \sigma_i^2. \tag{13}
\]

And the weight is

\[
w_i = \frac{1}{\sigma_i^2 \sum_{i=1}^{n} (1/\sigma_i^2)} \tag{14}\]

4. Results

The experimental environment of this paper selects pipa of different materials and completes the arrangement of five nodes as shown in Figure 3.

The parameter configuration module is utilized to complete the parameter setting during the identification process, and the command is delivered to the lower computer. Upon successful startup of the system, each terminal node recognizes and gathers the pipa strings. Afterward, it produces the appropriate tones. Based on identification readiness, Figure 4 depicts a comparison of our method with the classical wireless sensor identification methods WSI and TWSI.

Accordingly, the packet loss rate is used as the measurement index to count the number of packets lost in the data identification of the three techniques, with the packet loss rate being the most common. The statistical results are shown in the diagram below.

As shown in Figure 5, the proposed method has the lowest packet loss rate. It is primarily since the sensor network system has been completely calibrated, has a long stabilization period, consumes little power, is small in size, and shuts down automatically to ensure that data identification is accurate.

In conclusion, the suggested approach may be used to differentiate between the tones of pipa strings produced on different pipa panels, and it has some validity and feasibility in certain conditions.
5. Conclusion

Wireless sensor networks are rapidly developing, and their application fields are increasing daily. They have not limited themselves to the military industry anymore because of the rapid development of these networks. At this point, it has demonstrated a strong development tendency in social life and is steadily becoming more incorporated into people’s daily lives. With the use of duration tone identification, high degrees of tone recognition may be attained. In addition, tone perception is influenced by the amplitude contour and periodicity. According to the currently available pipa playing tone recognition method, there are issues with low accuracy and a high rate of data packet loss in the system. Based on wireless sensors, this research provides a tone detection technique for pipa strings that may be implemented in software. Following sensor stage and weight-corresponding characteristics, and under the assumption of minimization of the total mean square error, the optimal weight corresponding to the measured value of the sensor is found according to the adaptive mode, and the unbiased estimated value of the measured value of each node is obtained by iterative calculation. The creation of an adaptive weighted recognition algorithm is presented, as well as the conversion of binary recognition results. The experimental findings show that the recommended approach has high tone detection accuracy in this circumstance, using the pipa as a test instrument.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that he has no conflict of interest.

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