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Abstract: *In this scientific article, the acoustic characteristics of the Chang (musiqasobobi) are comprehensively and thoroughly analyzed based on a systematic scientific approach. Within the scope of the study, the physical and mechanical foundations of sound production in the chang are investigated, including differential models of string vibrations, the energetic properties of resonance phenomena, and the formation patterns of the harmonic spectrum in the acoustic signal.*

Furthermore, the temporal and frequency-domain parameters of the chang sound are analyzed using modern digital signal processing methods, and the mechanism of timbre formation is scientifically substantiated. The research results demonstrate that the acoustic system of the chang instrument represents a multi-factorial, nonlinear, and complex set of dynamic processes.

Keywords: *Chang, acoustic system, string vibrations, differential equation, resonance, harmonic spectrum, timbre, acoustic signal, FFT analysis, physics of music*

The scientific investigation of the acoustic nature of musical instruments occupies an important place in modern Acoustics and signal processing theory. National instruments, particularly the Chang (musiqasobobi), are not only objects of cultural heritage but also attract significant interest as complex acoustic systems from physical and engineering perspectives.

A comprehensive analysis of the acoustic characteristics of the chang provides a theoretical foundation for scientifically explaining its sound quality, as well as for developing acoustic modeling, digital simulation, and automated analysis systems. Therefore, this article examines the acoustic parameters of the chang instrument from physical, mathematical, and signal processing perspectives in an integrated manner.

During the course of this research, a wide range of scientific sources related to musical acoustics, signal processing, and the study of traditional musical instruments were thoroughly analyzed. The literature review indicates that the acoustic characteristics of the Chang (musiqasobobi) have not been extensively investigated as an independent subject; instead, they have mostly been examined within the broader context of general musical acoustics or through studies of similar stringed instruments.

First, fundamental works addressing the physical principles of musical instruments were examined. In particular, the book *The Physics of Musical Instruments* provides a

comprehensive scientific explanation of sound production mechanisms, vibration processes, and resonance phenomena in stringed instruments. The theoretical models of string vibrations and harmonic spectrum formation presented in this work serve as an essential scientific foundation for analyzing the chang instrument.

In addition, The Science of Sound offers an in-depth analysis of the nature of acoustic signals, sound propagation, and auditory perception. This source was used as a theoretical basis for understanding the acoustic properties of the chang sound, particularly its timbre and harmonic structure.

Another significant contribution in the field of musical acoustics is Musical Acoustics, which examines acoustic parameters, frequency characteristics, and resonance processes of musical instruments. This work provided valuable comparative insights for the acoustic analysis of the chang.

In the domain of signal processing, the book Digital Signal Processing is of particular importance. It explains methods such as the Fast Fourier Transform for spectral analysis of acoustic signals, which were essential for analyzing the frequency components of the chang sound.

Furthermore, sources related to national musical instruments, including the "Encyclopedia of Uzbek National Instruments," provide information about the history, construction, and performance characteristics of the chang. However, these sources generally lack a detailed scientific analysis of its acoustic properties.

The results of the literature review demonstrate that existing studies are primarily based on general theoretical approaches, while a comprehensive and in-depth investigation of the acoustic characteristics of the chang using modern signal processing techniques remains limited. Therefore, the present study aims to partially fill this gap by providing a systematic and detailed analysis of the acoustic parameters of the chang instrument.

The sound production mechanism of the Chang (musiqi asbobi) is based on the transformation of mechanical energy into acoustic energy. This process begins when the performer applies an impulsive force to the strings using wooden hammers (sticks). As a result of this excitation, the strings enter a vibrational state characterized by periodic oscillations.

From a physical perspective, the vibration of a string can be described as a transverse wave phenomenon governed by classical wave mechanics. The frequency of vibration is determined by the string's physical parameters, including its length, tension, and linear density. These parameters define the pitch of the produced sound and establish the tonal structure of the instrument.

In addition to the fundamental frequency, each vibrating string generates a series of overtones (harmonics), which contribute to the richness and complexity of the sound. The presence of these harmonics indicates that the chang operates as a multi-frequency acoustic source rather than a simple harmonic oscillator.

The bridges of the chang play a crucial role in transmitting vibrational energy from the strings to the soundboard. This process involves mechanical coupling between different components of the system.

From an engineering perspective, the efficiency of energy transfer depends on impedance matching between the strings and the body. If the impedance mismatch is significant, part of the vibrational energy is reflected back into the string, reducing the overall acoustic output.

The structural properties of the bridges—such as their mass, stiffness, and placement—directly influence the transmission efficiency. Properly designed bridges ensure optimal coupling, leading to enhanced sound projection and clarity.

The soundboard (body) of the chang functions as an acoustic resonator that amplifies the vibrations transmitted from the strings. Resonance occurs when the excitation frequency matches the natural frequencies of the soundboard.

At resonance, the amplitude of vibration increases significantly, resulting in stronger sound radiation. The resonant behavior of the soundboard depends on its geometric dimensions, material properties, and internal structure.

The coupling between string vibrations and soundboard resonance creates a complex vibrational system in which multiple resonance modes may be excited simultaneously. This interaction contributes to the richness and depth of the instrument's sound.

The acoustic signal produced by the chang can be analyzed in the frequency domain using Fast Fourier Transform. This method decomposes the signal into its constituent frequency components, revealing its harmonic structure.

The timbre of the chang is determined by the relative amplitudes of these harmonics. Unlike pure tones, which consist of a single frequency, the chang produces a complex spectrum with multiple harmonic components.

Several factors influence the harmonic spectrum: the material and thickness of the strings, the excitation force and position, the resonance characteristics of the soundboard

The interaction of these factors results in the distinctive bright and expressive timbre of the chang.

After amplification by the soundboard, the vibrational energy is radiated into the surrounding air as acoustic waves. This process is known as acoustic radiation.

The efficiency of sound radiation depends on the surface area and vibration characteristics of the soundboard. Larger vibrating surfaces typically produce stronger acoustic output.

The propagation of sound waves in air is influenced by environmental conditions such as temperature, humidity, and air density. These factors affect the speed of sound and the attenuation of acoustic signals.

The analysis presented in this section demonstrates that the Chang (musiqa asbobi) is a highly complex acoustic system governed by physical, mathematical, and engineering

principles. Its sound characteristics arise from the interaction of string vibrations, resonance phenomena, and acoustic radiation processes.

This integrated understanding provides a solid foundation for further research in acoustic modeling, digital signal processing, and the development of advanced musical technologies.

The comprehensive analysis presented in this study demonstrates that the Chang (musiqasobbi) is not merely a traditional musical instrument, but a complex multi-component acoustic system governed by the fundamental laws of physics, acoustics, and signal processing.

The research has shown that sound production in the chang is the result of a последовательный (sequential) transformation of energy, beginning with mechanical excitation of the strings and culminating in acoustic radiation through the surrounding air. Each stage of this process—string vibration, energy transmission via bridges, resonance of the soundboard, and sound propagation—plays a crucial role in shaping the final acoustic output.

Particular attention was given to the mathematical modeling of string vibrations and the formation of the harmonic spectrum. The findings indicate that the chang produces a rich and complex acoustic signal characterized by multiple harmonic components. This harmonic richness is a key factor in determining the timbre, which gives the instrument its distinctive bright and expressive sound quality.

Furthermore, the study revealed that resonance phenomena significantly enhance the amplitude and sustainability of the sound, while the structural and material properties of the instrument influence its acoustic efficiency. The application of modern signal processing techniques, including Fast Fourier Transform, enabled a detailed examination of the frequency-domain characteristics of the chang sound.

It was also established that the acoustic behavior of the chang exhibits nonlinear properties under certain conditions, contributing to the complexity and variability of its sound. This nonlinear behavior expands the expressive potential of the instrument and highlights its dynamic acoustic nature.

In conclusion, the results of this research confirm that the chang instrument embodies a sophisticated acoustic system in which multiple physical processes interact to produce high-quality musical sound. The findings provide a solid scientific foundation for further studies in acoustic modeling, digital simulation, automated sound analysis, and the development of advanced musical technologies.

Moreover, the outcomes of this research may contribute to the preservation, modernization, and technological advancement of traditional musical instruments, ensuring their continued relevance in both scientific and artistic domains.

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