



Quantum Theory and Harmonic Analysis of Sound: Foundations, Models and Implications

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ABSTRACT: This study introduces an innovative theoretical and analytical framework called Quantum Vocal Theory of Sound (QVTS), which applies the concepts of quantum mechanics to the modeling, analysis, and synthesis of sound, especially vocal and acoustic events. In contrast to traditional acoustics rooted in classical wave theory, QVTS views sound as a quantum phenomenon, defined by superposition, coherence, and entanglement among essential phonatory states like phonation, turbulence, and myoelastic vibrations. The research presents Quantum Harmonic Analysis (QHA) as a fundamental mathematical instrument, extending Fourier and wavelet transforms into Hilbert-space frameworks directed by quantum operators. In this process, sound is broken down into quantized spectral elements, enabling accurate analysis of phonon interactions, harmonic structures, and random fluctuations. The study additionally develops quantum-analog correspondences between human vocal apparatus and quantum entities, like spin states and qubits, to introduce a novel framework for voice-based sound modeling and auditory scene interpretation. This theoretical development connects auditory perception, speech acoustics, and quantum-inspired signal processing, creating new avenues in quantum acoustic synthesis, quantum-based sonification, and voice-controlled quantum computing systems. The results illustrate the capability of QVTS to integrate physical acoustics with the principles of quantum computation, thus providing a fundamental advancement toward a quantum structure for sonic intelligence and sound-oriented information processing.

Keywords: Sound, superposition, spin, audio, physics, acoustics, music, quantum harmonic analysis.

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1. Introduction

The Quantum Theory of Sound [1] is a developing multidisciplinary idea that makes comparisons between the tenets of quantum mechanics [14] and the vibrational actions of the human voice [6]. While traditional vocal science explains sound production through mechanical and acoustic means, this theory introduces an innovative paradigm: considering the voice as a quantum-like entity in which sound states can exist in superpositions, move between distinct energy levels, and display characteristics similar to wave-particle duality or entanglement.

At its essence, the theory aims to investigate if the intricate harmonic richness of vocal sound, especially in subtle techniques such as overtone singing [18], vibrato, or emotionally charged speech, can be understood using the mathematical concepts and metaphors of quantum physics [14]. This involves representing vocal formants as discrete modes, studying emotional timbre as probabilistic state reductions, or even employing quantum algorithms to simulate or analyze vocal signals.

While not asserting a direct quantum function in biological vocal cords, Quantum Vocal Theory offers a strong conceptual framework that could improve sound synthesis, voice training, psychoacoustics, and therapeutic sound uses. It paves the way for advanced explorations of sound, awareness, and self through the terminology of quantum science.

2. Literature Review

2.1. A Quantum Vocal Theory of Sound

This text outlines the fundamental framework of Quantum Vocal Theory of Sound (QVTS) [1], proposing that aspects of vocal production, like phonation, turbulence, and supraglottal vibrations, can be depicted as quantum states. By using analogies from quantum spin systems, the authors suggest that these components may exist in superposition and engage in quantum-like interactions. The framework promotes reconsidering sound synthesis and analysis through the application of quantum mechanical principles such as measurement, observables, and time evolution to represent sound behavior in an innovative and mathematically organized manner [1].

2.2. Quanta in Sound, the Sound of Quanta: A Voice-Informed Quantum Theoretical Perspective on Sound

This subsequent paper expands the QVTS [1] framework by officially defining “phons” as the tiniest units of vocal sound, similar to quantum particles. The writers highlight the importance of voice and vocal imitation in shaping sound as a human experience. They elaborate on quantum observables and measurement techniques to clarify how vocal components can exist in superposed states and how these can be controlled for sound synthesis. The study connects the perception and creation of sound to embodied cognition and suggests employing quantum logic as a tool for analysis in sonic interaction design [29].

2.3. Playing Pool with $|\psi\rangle$: From Bouncing Billiards to Quantum Search

This work introduces a classical counterpart to Grover’s quantum search algorithm [3] using a physical setup involving two colliding billiard balls. The writer demonstrates that the elastic collision process involving a heavy ball and a light ball resembles quantum amplitude amplification via repetitive reflections of states. The velocity space of the billiard system aligns with the quantum state space, and every collision functions as a quantum-like rotation. While not explicitly concerning sound, this piece provides significant educational value by rendering quantum computational dynamics visually and intuitively comprehensible, possibly motivating analogous models in QVTS [30].

2.4. Hear the Sound of Weyl Fermions

This study examines a quantum mechanical acoustic mode referred to as chiral zero sound (CZS) in Weyl semimetals. In contrast to conventional sound modes, CZS is a neutral excitation arising from the chiral magnetic effect in the presence of a magnetic field. The writers suggest that this sound travels without charge and is affected by the topological characteristics of matter. While rooted in condensed matter physics instead of vocal acoustics, this study creates opportunities to comprehend unusual sound phenomena through a quantum lens, enhancing the theoretical framework related to quantum acoustics [31].

3. Research Gaps

A Quantum Vocal Theory of Sound is not a conventional or well-known academic model within physics, phonetics, or acoustics, indicating it could be speculative, metaphorical, or derived from a specialized or interdisciplinary viewpoint (for instance, merging quantum theory with vocal studies, philosophy, or even new age concepts). However, if the theory seeks to utilize quantum principles (such as wave-particle duality, superposition, or entanglement) in relation to the creation, perception, or composition of sound, particularly vocal sound, there are fascinating opportunities and significant gaps in the area that warrant examination.

3.1. Modelling Sound using Quantum Analogies

Opportunity: Creating mathematical models that regard vocal signals (or their elements) as quantum wavefunctions to gain deeper insights into subtle changes, including glottal pulses or microtonal variations.

Research Question: Is it possible to model features of vocal modulation (e.g., vibrato, shifts in timbre) [4] using concepts such as quantum superposition or coherence?

3.2. Quantum Acoustic Simulation

Opportunity: Explore whether quantum computing [12] can simulate acoustic waveforms or vocal behaviors [6] more effectively than traditional models.

Research Question: Is it possible for a quantum algorithm to replicate the intricate harmonics of the human voice [6] more effectively than existing Fourier-based or deep-learning models?

3.3. Nonlinear Dynamics and Uncertainty in Vocal Production

Opportunity: Investigate if the Heisenberg Uncertainty Principle [7] has symbolic or analytical applications in depicting the compromises between accuracy in vocal pitch and clarity over time.

Gap: There is an absence of formal studies linking uncertainty in vocal tract modeling to quantum principles. The typical non-linear distribution of vocal production is as shown in Figure 1. Research into introducing nonlinearities in quantum algorithms are evolving.

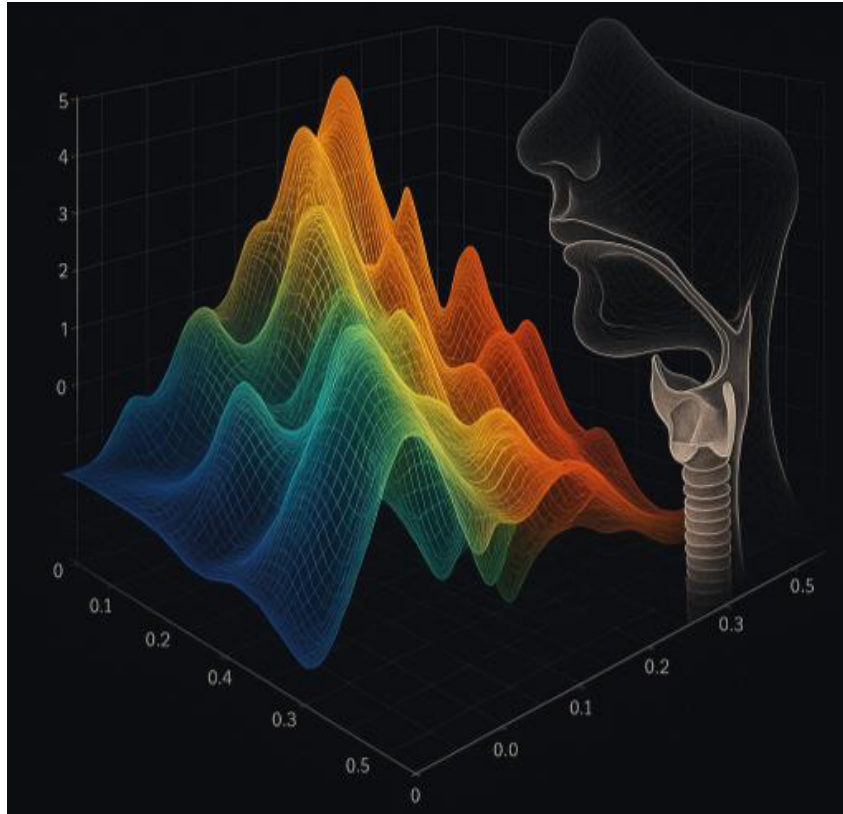


Figure 1: Image representing Nonlinear Dynamics and Uncertainty in Vocal Production.

3.4. Entanglement in Communication

Opportunity: Explore, either metaphorically or literally, whether “entangled” vocal states, such as simultaneous multilingual speech or harmonic overtones, can be explained using quantum entanglement frameworks.

Philosophical Perspective: In what way do speaker and listener “exchange” information—does vocal sound hold hidden variables that only become defined upon perception?

3.5. Psychoacoustics and Quantum Perception

Opportunity: Explore if human auditory perception of sound encompasses quantum effects, as suggested by certain researchers in the wider domain of neuroquantology [8,9,10].

Gap: Empirical neuroscience has yet to establish a clear connection between quantum processes and auditory perception, maintaining an unresolved area of research.

4. Gaps and Weaknesses

The following are the gaps and weaknesses of the current theoretical framework.

4.1. Lack of Empirical Basis

Quantum phenomena [11] are typically observable at atomic scales, while sound and voice are macroscopic. In the absence of direct measurements, the theory may end up being metaphorical instead of providing physical explanations. This essential scale disparity prompts significant inquiries regarding the physical relevance of quantum mechanics to acoustics [15]. In classical physics, sound is viewed as a pressure wave following Newtonian and thermodynamic principles, whereas quantum systems exhibit probabilistic state changes, superposition, and non-locality—traits that do not directly appear in typical vocal activities. It may act as a conceptual or computational comparison instead of a theory grounded in physical reality. For instance, employing quantum superposition to depict the intricacies of overlapping formants or utilizing state transitions to represent pitch variations can provide valuable insights, yet these do not inherently indicate the existence of quantum coherence or entanglement in vocal anatomy. If the theory lacks empirical backing or fails to connect with mesoscopic or hybrid quantum systems, it is more probably a creative model rather than a factual representation of how sound and voice operate physically.

4.2. Terminological Ambiguity

Numerous so-called “quantum” theories beyond physics incorrectly apply or misinterpret concepts such as entanglement and duality. A significant shortcoming is the absence of strict definitions and the inability to be proven false. These concepts, with exact mathematical definitions and testable consequences in quantum mechanics, are frequently adapted and loosely redefined in areas like psychology, philosophy, art, and even acoustics. Although interdisciplinary metaphors can ignite creativity and foster innovative frameworks, issues occur when these metaphors are framed as scientifically sound theories that lack precise definitions or verifiable claims. In authentic quantum physics, a theory should provide accurate predictions that can be confirmed or disproven via observation and experimentation. Conversely, numerous extrapolated “quantum” models fail to clearly define their terminology, lack formal mathematical structure, and frequently cannot be falsified, positioning them beyond the domain of empirical science.

4.3. Interdisciplinary Isolation

It appears that there is minimal peer-reviewed research connecting quantum physics directly to vocal acoustics. Cooperation among physics, phonetics, and AI would be essential to advance this into a verifiable theory. Although exploratory frameworks like the Quantum Vocal Theory of Sound suggest conceptual parallels between quantum systems and vocal behavior, such as representing pitch states or resonances as quantized energy levels, these concepts primarily lack empirical validation and remain largely theoretical. The core challenge is to align the microscopic aspects of quantum mechanics with the macroscopic, biomechanical mechanisms of human voice production [6,16] which are typically effectively explained by classical physics and fluid dynamics. Physicists offer the mathematical framework and experimental knowledge needed to establish quantum models with precision. Specialists in phonetics and vocal physiology provide expertise on the generation and perception of sound, guaranteeing that suggested models stay rooted in biological truth. In the meantime, experts in artificial intelligence and machine learning [17] can connect theory and data, creating models that analyze voice patterns, replicate state changes, or even evaluate theoretical “quantum” traits using extensive acoustic datasets.

4.4. Computational Inaccessibility

Quantum computing is not currently available or effective enough for the extensive simulation of real-time voice models. Any theory that relies on this will stay theoretical for the time being. Present quantum devices are restricted by low qubit numbers, brief coherence durations, and high error rates, making them inadequate for extensive simulations that involve the dynamic, high-resolution data necessary for acoustic modeling. Mimicking human voice, particularly through quantum-inspired systems with various interacting “vocal states”, transitions, and time-varying waveforms [23], would require a degree of quantum computational capability that surpasses existing resources. Although quantum algorithms such as Grover’s and the quantum harmonic oscillator model [22,24] provide intriguing perspectives on representing or abstracting specific acoustic phenomena, they have yet to be implemented in practical, real-time systems.

5. Forward Looking Research Directions

Here are some forward looking research directions:

- Create computational frameworks that simulate vocal signal processing to reflect quantum phenomena (for example, harmonics in superposition).
- Examine the boundaries of classical acoustics and recognize where “quantum-like” behavior (such as probabilistic behavior and chaotic transitions) is already evident.
- Investigate neuromechanics [20] to determine whether the brain employs quantum-like processing for auditory perception [8], similar to quantum cognition [21] theories.
- Initiate interdisciplinary symposia that connect voice studies, quantum computing, and acoustic modelling.
- The Quantum Harmonic Oscillator (QHO) can greatly improve studies in the Quantum Vocal Theory of Sound (QVTS) by offering a precise, quantized structure for simulating vocal dynamics like pitch, resonance, and register shifts. In this framework, vocal components such as glottal vibrations and formant patterns may be compared to quantized energy states, where varying pitches [13] relate to distinct oscillator levels. This enables researchers to model pitch transitions, vibrato, and phonation alterations as state changes in the QHO, providing a wave-oriented and probabilistic view of vocal behavior. Additionally, features obtained from QHO, like energy level occupancy, transition rates, and state entropy, can improve machine learning models for recognizing vocal emotions or for vocal synthesis. Incorporating QHO principles into QVTS effectively connects acoustic modelling with quantum mathematics, creating innovative opportunities for analytical accuracy, dynamic vocal synthesis, and cross-disciplinary exploration.

6. Models and Simulations

The following are the models and simulations which are used to study Quantum Vocal Theory of Sound (QVTS).

6.1. Quantum Harmonic Oscillator

The Quantum Harmonic Oscillator (QHO) is a fundamental model in quantum mechanics that describes a particle oscillating around a stable equilibrium point, similar to how a mass on a spring behaves in classical physics, but governed by quantum rules. The QHO models systems like vibrating atoms, photons in a cavity, or phonons in a crystal. The QHO [22] model is employed to illustrate the oscillatory characteristics of vocal components like phonation, turbulence, and supraglottal myoelastic vibrations. These elements are considered quantized energy states, enabling the examination of their interactions and transitions throughout time. Within this framework, these vocal components, usually represented through traditional acoustics and biomechanics, are redefined as quantized energy states, akin to the distinct vibrational levels of particles within a harmonic potential in quantum mechanics. This comparison allows every vocal state or gesture (such as a certain pitch, resonance, or airflow variation) to be linked to a specific energy level in the oscillator model. For example, pitch modulation, register changes, or formant shifts can be represented as quantum-like transitions between states (e.g., from $n = 1$ to $n = 2$), providing a framework to mathematically illustrate vocal dynamics.

6.2. Spin State Analogies

QVTS makes comparisons between vocal states and quantum spin [25] states. This method represents the combination and entanglement of various vocal elements, enhancing the comprehension of how intricate sounds are created and experienced. In quantum physics, spin states can be in superposition and become entangled, implying they can maintain several configurations at once and affect each other in complex manners. QVTS utilizes this conceptual framework for vocal production, proposing that phonation, turbulence, resonance, and additional vocal components can similarly be perceived as coexisting or interacting conditions within a cohesive vocal quantum system. For instance, a vocalist’s voice could

convey tonal steadiness (phonation) and breathiness (turbulence) at the same time, which in QVTS might be understood as a combined or intertwined state instead of two distinct occurrences.

6.3. Gabor Analysis

Building on Dennis Gabor’s research [26], QVTS integrates time-frequency analysis techniques to explore the time-based development of vocal sounds. This enables the breakdown of sounds into basic elements, facilitating both analytical and synthesizing activities. Gabor’s framework, which formed the basis for the short-time Fourier transform and subsequently wavelet analysis, highlights the dual aspect of sound as a function of time and frequency—this concept resonates with the tenets of quantum mechanics, especially the uncertainty principle connecting time and energy. QVTS builds on this concept by perceiving vocal sounds as combinations of intermingling, quantum-like states that develop over time. By utilizing time-frequency analysis, intricate vocal expressions, like changes between registers, variations in tone intensity, or swift alterations in pitch, can be broken down into a collection of basic acoustic quanta. Integrating Gabor’s time-frequency principles into its framework, QVTS utilizes a robust analytical toolkit that connects traditional signal processing for research and innovative sound design.

6.4. Harmonic plus Stochastic (HPS) Model

The HPS model is used to differentiate between the harmonic (regular) and stochastic (noise-like) elements of vocal signals. This distinction is essential for effectively modelling and creating authentic vocal sounds. Within the framework of the Quantum Vocal Theory of Sound (QVTS), incorporating this model enhances the understanding of intricate vocal behavior. Human vocal signals seldom consist solely of pure tones or noise; instead, they feature a dynamic interaction between organized harmonics (such as those produced by vocal fold vibrations) and chaotic noise elements (stemming from turbulent airflow, aspiration, or breathiness). The HPS model allows for a more detailed breakdown of these elements by distinguishing the periodic, pitch-related parts from the non-periodic, chaotic parts. This is especially crucial in expressive speech [28] and singing, where elements such as vibrato, vocal fry, or whispered tones blend harmonic and stochastic content in different ratios.

7. Quantum Harmonic Analysis of Human Voice

The Quantum Harmonic Analysis of the Human Voice is an investigative framework that employs concepts from quantum mechanics, especially the quantum harmonic oscillator (QHO), to the sound characteristics of the human voice.

Conventional voice analysis depends on Fourier transforms and formant tracking to assess pitch, timbre, and resonance. Conversely, this method views the vocal tract as a potential well [19] and simulates vocal vibrations as quantized oscillatory states, similar to energy levels in a quantum harmonic oscillator (QHO).

This theoretical perspective connects physics and voice science, suggesting that the frequency spectrum of the vocal signal may display patterns similar to the distinct eigenstates observed in quantum systems. The goal is not to imply actual quantum activity in the larynx, but to utilize quantum frameworks as symbols or mathematical representations for improved comprehension, simulation, or even enhancement of voice synthesis, analysis, or training.

8. Methodology

The Road to Phase 2 involves a hands-on Quantum Harmonic Analysis of The Human Voice by implementing a Quantum Harmonic Oscillator Simulation using Python. Google Colab and some Python libraries are used to do this. The following are the tools to do so.

8.1. Software: Audacity

Audacity (License: GNU GENERAL PUBLIC LICENSE) is an open-source software for digital audio editing and recording, accessible for Windows, macOS, Linux, and other Unix-based operating systems. It is popular among podcasters, musicians, and audio engineers for its powerful features and cross-platform compatibility. It allows viewing, editing, and manipulating of sound waveforms visually.

8.2. Python Libraries

- **librosa:** librosa is a Python library designed for analyzing music and audio. librosa is primarily utilized when handling audio data, such as in music creation (using LSTMs) and Automatic Speech Recognition.
- **qutip:** QuTiP, which stands for the Quantum Toolbox in Python, is a free software library for computational physics designed to simulate quantum systems, especially open quantum systems. QuTiP enables the simulation of Hamiltonians with any time-dependence, facilitating the exploration of scenarios relevant to quantum optics, ion trapping, superconducting circuits, and quantum nanomechanical resonators.
- **matplotlib:** Matplotlib is a powerful and widely-used Python library employed for visualizing data. It allows you to create numerous static, interactive, and animated visualizations in Python.

8.3. Steps and Purpose

Here are the following steps:

1. Record voice/download audio or generate tone using Audacity and save it.
2. **Setup & Libraries:** Install and import necessary Python libraries for audio analysis (librosa), quantum simulation (qutip), and visualization (matplotlib).
3. **Load Audio:** Upload a WAV file and extract waveform data (y) and sample rate (sr).
4. **Pitch Extraction:** Use `librosa.pyin()` to compute the fundamental frequency (f_0) over time. Visualize the pitch contour.
5. **Spectrogram Visualization:** Generate and display a spectrogram to show time-frequency content of the vocal signal.
6. **Pitch-to-Quantum Mapping:** Map each pitch value to a quantized energy level (n) using a logarithmic scale (based on semitone intervals from A3). Plot these states over time to visualize pitch transitions as quantum-like state jumps.
7. **Quantum Harmonic Oscillator Simulation:** Simulate the first five eigenstates (wavefunctions) of a quantum harmonic oscillator using qutip. Plot the probability densities $|\psi_n(x)|^2$ to show how energy is spatially distributed in each state.
8. **Entropy Calculation:** Compute the Shannon entropy of the pitch distribution to quantify variability or “uncertainty” in vocal expression.

8.4. Code

The following Python code implements the Quantum Harmonic Analysis:

Listing 1: Python implementation of Quantum Harmonic Analysis

```

1  # STEP 1: Install necessary libraries
2  !pip install librosa qutip numpy matplotlib scipy --quiet
3
4  # STEP 2: Import libraries
5  import librosa
6  import librosa.display
7  import qutip as qt
8  import numpy as np
9  import matplotlib.pyplot as plt
10 import scipy.stats
11 from google.colab import files
12
13 # STEP 3: Upload voice audio
14 print("Upload a WAV audio file of your voice...")

```

```

15     uploaded = files.upload()
16     filename = next(iter(uploaded))
17
18     # STEP 4: Load audio
19     y, sr = librosa.load(filename)
20     print(f"Audio file loaded: {filename}")
21     print(f"Duration: {len(y)/sr:.2f}s, Sample Rate: {sr}Hz")
22
23     # STEP 5: Pitch extraction using librosa.pyin
24     f0, voiced_flag, voiced_probs = librosa.pyin(
25     y, fmin=librosa.note_to_hz('C2'),
26     fmax=librosa.note_to_hz('C7'))
27     times = librosa.times_like(f0)
28
29     # STEP 6: Plot spectrogram
30     D = librosa.amplitude_to_db(np.abs(librosa.stft(y)), ref=np.max)
31
32     # STEP 7: Map pitch to quantized quantum states
33     def pitch_to_qstate(frequency, base_freq=220.0):
34     if frequency is None or np.isnan(frequency):
35     return None
36     ratio = frequency / base_freq
37     return int(np.round(np.log2(ratio) * 12 / 2))
38
39     q_states = [pitch_to_qstate(f) for f in f0]
40
41     # STEP 8: Quantum Harmonic Oscillator wavefunction
42     from scipy.special import hermite
43     from math import factorial, sqrt, pi
44
45     def psi_n(x, n, width=1.0):
46     Hn = hermite(n)
47     norm_const = 1.0 / sqrt((2**n) * factorial(n) * sqrt(pi) * width)
48     return norm_const * np.exp(-(x/width)**2 / 2) * Hn(x/width)
49
50     # STEP 9: Calculate entropy of the pitch distribution
51     clean_f0 = [f for f in f0 if f is not None and not np.isnan(f)]
52     hist, bins = np.histogram(clean_f0, bins=20, density=True)
53     entropy = scipy.stats.entropy(hist)
54     print(f"Entropy of voice pitch: {entropy:.3f}")

```

8.5. Results

8.5.1. *Sample 01: Logarithmically Increasing Pitch of a Square Wave.* Entropy = 2.993: moderate uncertainty, showing varied but structured pitch progression.

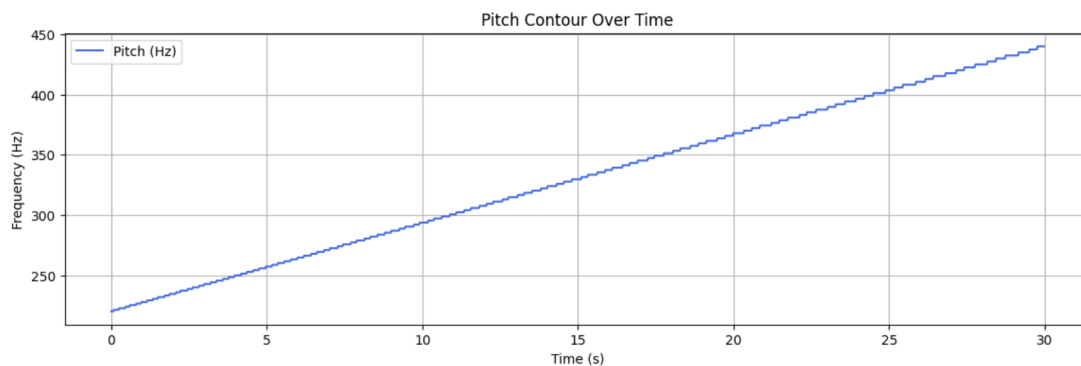


Figure 2: Pitch Contour of Logarithmically increasing pitch of a square wave.

A logarithmically increasing pitch in a square wave would result in a pitch contour that rises smoothly, linearly and continuously as shown in Figure 2, as perceived by humans, is directly related to the frequency of a sound wave. Higher frequencies correspond to higher pitches.

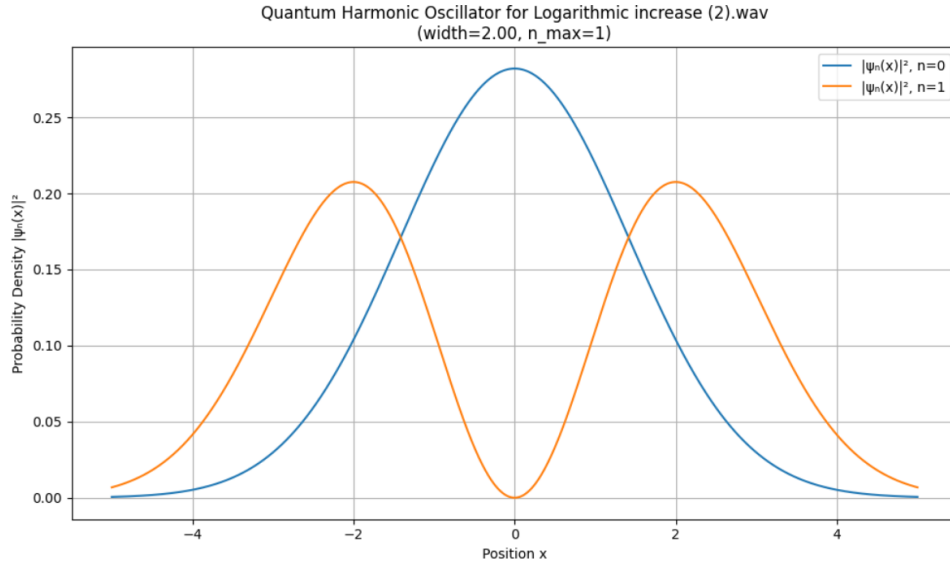


Figure 3: QHO of a square wave with logarithmically increasing pitch.

This graph in Figure 3 displays $|\psi_n(x)|^2$ for a Quantum Harmonic Oscillator with a width of $w = 2.0$. The wavefunction is:

$$\psi_n(x) = H_n \left(\frac{x}{w} \right) e^{-\frac{x^2}{2w^2}} \times \frac{1}{\sqrt{2^n n! \sqrt{\pi} w}} \quad (8.1)$$

where H_n denotes the n th Hermite polynomial. For $n = 0$, $|\psi_0(x)|^2$ appears as a singular Gaussian peak located at $x = 0$, indicating that the particle is highly probable to be close to equilibrium. For $n = 1$, the probability density features two symmetric peaks and a node at $x = 0$, resulting from the sign change of $\psi_1(x)$ at the origin. The parameter w determines the overall distribution of the curves.

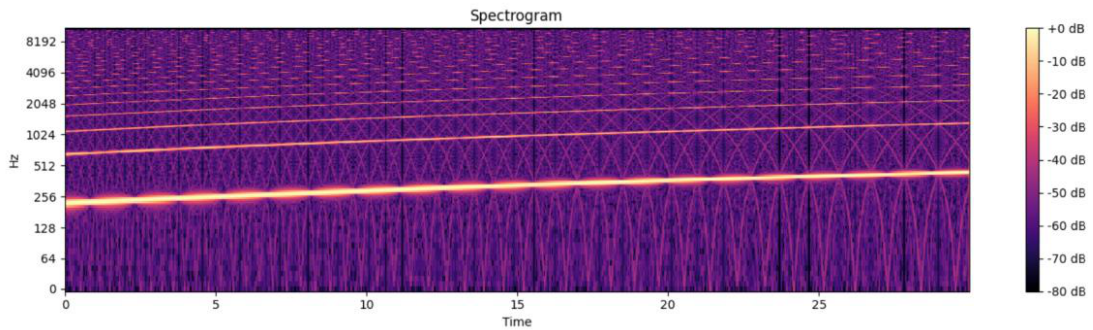


Figure 4: Spectrogram of a Logarithmically increasing pitch for a square wave.

This spectrogram in Figure 4 displays a square wave with a pitch that rises logarithmically as time progresses. The vivid horizontal lines indicate the fundamental frequency and its odd harmonics, a characteristic aspect of square waves. As time goes on, the base frequency increases along a curved

(logarithmic) trajectory, and the harmonics move upward in sync, preserving their spacing in frequency ratios.

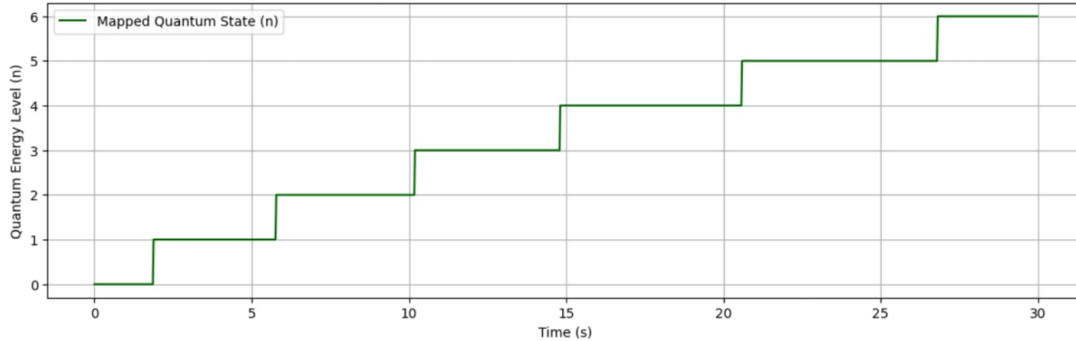


Figure 5: Mapped Quantum States of a square wave with logarithmically increasing pitch.

This graph in Figure 5 displays the plotted quantum energy level n over time for a square wave with a logarithmically increasing pitch. The step-like pattern arises as the constantly increasing pitch is distinctly assigned to integer quantum states according to set frequency limits. When the pitch surpasses each threshold, the system leaps to the subsequent n -level, creating unique flat sections followed by upward increases.

Highlights of Sample 01:

- The pitch rises smoothly from 220 Hz to 440 Hz, confirming a controlled logarithmic glissando.
- The spectrogram shows stable odd harmonics, rising consistently with the fundamental frequency.
- The mapped quantum states increase stepwise from $n = 0$ to $n = 6$, indicating discrete state transitions.
- QHO probability densities show wider distributions and additional oscillatory nodes at higher n -values.
- Entropy = 2.993, reflecting structured but moderate pitch uncertainty.
- These findings confirm that a monotonic pitch increase can be viewed as progressive transitions in a quantized acoustic state-space.

8.5.2. *Sample 02: Extinct Kauai O’O Bird.* Entropy = 2.612: moderate pitch uncertainty, less structured than a smooth tone but not fully random.

This pitch contour chart in Figure 6 illustrates the frequency changes over time for the recorded call of the extinct Kauai O’O bird. The graph displays a range of uneven frequency shifts and spaces, suggesting that the bird’s song comprised separate, high-frequency whistles and calls instead of smooth tones. The broad spectrum, spanning approximately 250 Hz to more than 2000 Hz, indicates the species’ incorporation of both low and high pitch components in its sounds.

This Quantum Harmonic Oscillator (QHO) graph in Figure 7 depicts the sound of the Kauai O’O bird by utilizing wavefunctions for state values $n = 0$ to $n = 3$ with a width of 0.5. The curves illustrate the probability density for every energy level, where $n = 0$ represents the ground state featuring a single central peak, while larger n values exhibit additional peaks and a greater spread. The slender peaks arise from the reduced width value, indicating that the wavefunctions are more concentrated.

This spectrogram of the now-extinct Kauai O’O bird in Figure 8 illustrates the variation in the sound’s frequency composition over time. Vivid yellow and orange regions signify higher intensities, whereas deeper hues denote lower sounds. The call of the bird manifests as clear, sporadic bands within the mid-to-high frequency range (approximately 1–4 kHz), mirroring its piercing, whistle-like tones.

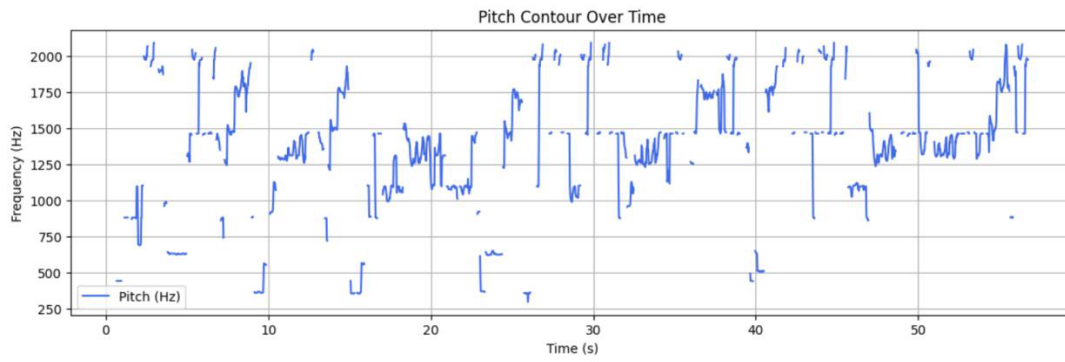


Figure 6: Pitch Contour of an Extinct Kauai O'O bird sound.

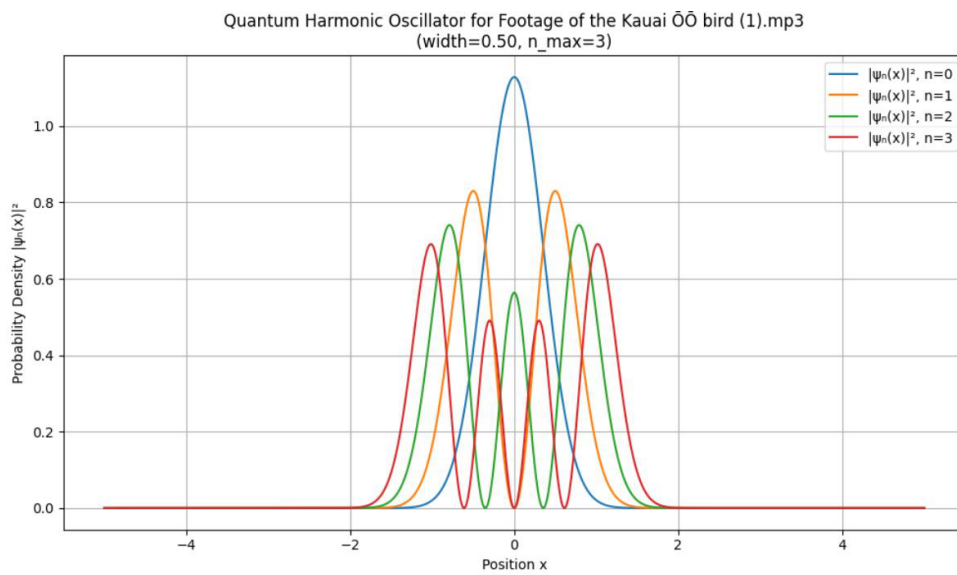


Figure 7: QHO of an Extinct Kauai O'O bird sound.

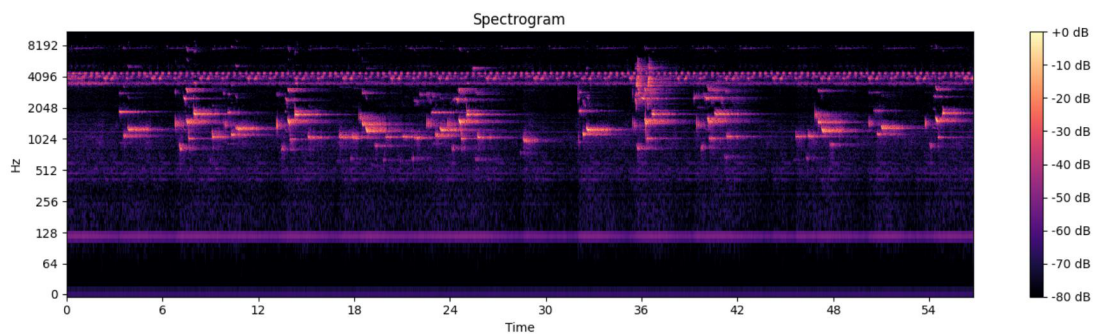


Figure 8: Spectrogram of an Extinct Kauai O'O bird sound.

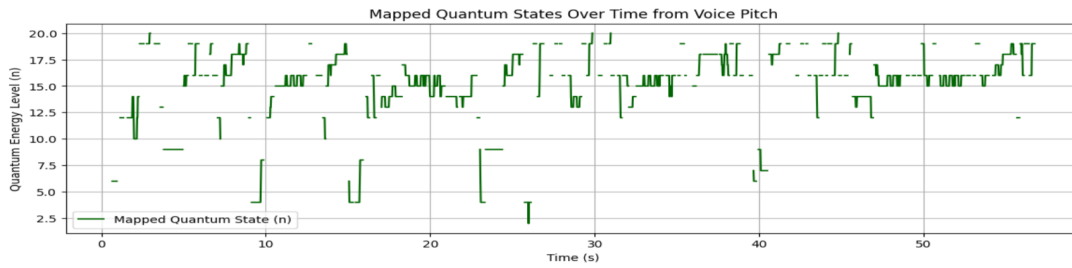


Figure 9: Mapped Quantum states of an Extinct Kauai O’O bird sound.

This graph in Figure 9 displays the recorded quantum energy levels (n) over time derived from the pitch of the Kauai O’O bird’s call. The constant shifts between energy levels illustrate the bird’s quick pitch alterations and diverse tonal framework.

Highlights of Sample 02:

- The pitch varies widely from ~ 300 – 2000 Hz, showing irregular, jumpy contours typical of bird vocalization.
- The spectrogram displays fragmented harmonics and high-frequency bursts, indicating rapidly changing acoustic energy.
- QHO probability densities ($n = 0$ – 4) show narrow, sharp peaks, consistent with the sound’s concentrated energy distribution.
- Entropy = 2.612, indicating moderate uncertainty but more disorder than the square-wave tone.
- These results show that natural bird calls produce nonlinear, broadly distributed quantum-state transitions.

9. Applications of QHO

Below are the applications of the Quantum Harmonic Oscillator.

9.1. Molecular Vibrations

In molecular systems, atoms vibrate about their equilibrium positions. These vibrations can be represented as quantum harmonic oscillators, particularly during minor oscillations. This approximation is crucial in vibrational spectroscopy methods such as infrared (IR) and Raman spectroscopy, where shifts between vibrational energy states offer insights into molecular structures and bonding. In this model, every vibrational mode of a molecule acts as a one-dimensional harmonic oscillator with distinct energy levels, where the energy of each level is determined by the vibrational quantum number n .

9.2. Phonons in Solids

In solid-state physics, atoms in a crystal lattice vibrate collectively and these vibrations are quantized as phonons. The QHO model characterizes these quantized vibrational modes, essential for comprehending thermal properties, electrical conductivity, and sound transmission in materials. Understanding these quantized vibrational modes is crucial for explaining several key material properties:

- **Thermal Properties:** Phonons are crucial in determining heat capacity and thermal conductivity.
- **Electrical Conductivity:** In materials, particularly in semiconductors and metals, phonons may scatter charge carriers (electrons and holes), which impacts mobility and resistivity.
- **Sound Transmission:** Because sound waves in solids travel as elastic vibrations, their quantum representation relates to acoustic phonons.

9.3. Quantum Field Theory and Photons

Every mode of the electromagnetic field can be regarded as a quantum harmonic oscillator. Quantizing these modes results in the idea of photons, which are the fundamental particles of light. This structure is crucial in quantum electrodynamics and the wider domain of quantum field theory. This oscillator-based field quantization also underpins advanced technologies and concepts:

- Lasers depend on stimulated emission, where the quantum description of light as photons is essential.
- Quantum optics explores the behavior of light in non-classical states (like squeezed or entangled states), requiring the full oscillator formalism.
- Cavity QED studies how a quantized EM field interacts with atoms or quantum dots in confined geometries.
- Photonic quantum computing uses individual photons as qubits, leveraging the controlled creation and manipulation of EM field modes.

9.4. Approximation of Potential Wells

Many potential energy wells in quantum systems [5] can be approximated as harmonic near their minima. This makes the QHO a valuable tool for approximating the behavior of particles in various potential landscapes, facilitating analytical solutions where exact ones are intractable. Any smooth potential function $V(x)$ can be expanded around a local minimum x_0 as:

$$V(x) \approx V(x_0) + \frac{1}{2}V''(x_0)(x - x_0)^2 + \dots \quad (9.1)$$

This transforms the complex potential into a form that resembles a harmonic oscillator potential:

$$V(x) \approx \frac{1}{2}m\omega^2(x - x_0)^2 \quad (9.2)$$

This leads directly to the quantum harmonic oscillator model, which has well-known, exact analytical solutions for the energy eigenvalues and eigenfunctions:

$$E_n = \hbar\omega \left(n + \frac{1}{2} \right) \quad (9.3)$$

9.5. Quantum Optics and Coherent States

In quantum optics, the QHO framework supports the explanation of coherent states [2], which closely mimic classical light waves. These states are crucial for comprehending laser function and the dynamics of light in optical cavities. A coherent state, typically denoted as $|\alpha\rangle$, is defined as an eigenstate of the annihilation operator \hat{a} associated with the quantum harmonic oscillator:

$$\hat{a}|\alpha\rangle = \alpha|\alpha\rangle \quad (9.4)$$

where α is a complex value associated with the amplitude and phase of the classical electromagnetic wave.

9.6. Educational Paradigm

The QHO is among the rare quantum systems that have precise analytical solutions. The course familiarizes students with essential quantum principles such as quantization, zero-point energy, and ladder operators, establishing it as a key component in quantum mechanics instruction. Through the study of the QHO, students are introduced to several fundamental quantum mechanical concepts:

- **Quantization of Energy:** Unlike classical systems where energy is continuous, the QHO reveals that energy levels are discrete.
- **Zero-Point Energy:** Even in its ground state ($n = 0$), the oscillator possesses a non-zero energy, reflecting the inescapable fluctuations due to the Heisenberg uncertainty principle.
- **Ladder Operators:** A unique and elegant feature of the QHO is its solution via the algebraic method, using operators \hat{a}^\dagger (creation) and \hat{a} (annihilation) that raise and lower energy eigenstates.

10. Conclusion

The Quantum Vocal Theory of Sound (QVTS) presents a framework that utilizes principles of quantum mechanics to examine and produce sound, especially human vocal expressions. By representing vocal components like phonation, turbulence, and supraglottal myoelastic vibrations as quantum states, QVTS allows for sound to be depicted as a superposition of these states. This method enhances comprehension of the temporal development of vocal sounds and lays the groundwork for innovative sound processing methods. Additionally, QVTS provides a rich environment for collaborative efforts between physicists, computer scientists, musicians, and sound designers, which could result in innovative approaches to auditory creativity and advancements in sound design and analysis.

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