Report

ProstheticQFT - Merging Quantum Fourier Transform with Fast Fourier Transform to Improve the Functionality of Prosthetic Ears.

BY: Jessica Omuna Anabor
FOR: DoraHacks MIT IQuHACK 2025

INTRODUCTION

What is the Function of a Prosthetic Ear?

A prosthetic ear is primarily intended to restore or improve auditory perception. It operates by capturing sound and processing it, typically utilizing microphones and digital signal processing (DSP) algorithms. The mechanism involves detecting sound waves, converting them into electrical signals, and employing algorithms (such as **Fourier Transforms**) to analyze and filter the frequencies before converting them back into signals that the user can perceive.

The Role of Fourier Transforms (FFT) in a Prosthetic Ear:

The classical FFT is extensively utilized in signal processing to convert time-domain data (sound signals) into the frequency domain. Its functions include:

- Extracting frequency components from sound signals.
- Filtering out noise by isolating and concentrating on specific frequency ranges.
- Enhancing particular sounds, such as distinguishing speech from background noise.

The FFT is essential in both traditional hearing aids and prosthetic ears, as it aids in determining which frequencies are significant and how to amplify or diminish certain sound components.

The Role of Quantum Fourier Transform (QFT):

Conversely, the Quantum Fourier Transform (QFT) represents a quantum computing method that can be regarded as a quantum adaptation of the classical FFT. Although QFT remains largely theoretical or experimental in many domains, it holds the potential to transform data analysis, particularly in managing large and intricate data sets (such as sound signals).

The QFT offers several advantages:

- **Speed and efficiency:** In theory, a quantum computer could execute a Fourier Transform at an exponentially faster rate than a classical computer, particularly with very large data sets.
- **Parallelism:** Quantum computing inherently facilitates parallel processing, which may result in quicker and more efficient sound data processing.
- **Managing complex data:** Quantum computers are inherently equipped to handle certain types of complex signals that classical algorithms struggle to process within a reasonable timeframe.

## The Potential Application of Quantum Computing in Signal Processing

The application of quantum computing, particularly in the realm of quantum signal processing, holds promise for advancing the functionality of prosthetic hearing devices in their sound processing and interpretation capabilities. The code available on GitHub demonstrates a simulation that illustrates how intricate sound signals, akin to those received by a prosthetic ear, can be optimized through quantum methodologies such as the Quantum Fourier Transform and quantum classifiers. This innovation may lead to enhanced efficiency, accuracy, and adaptability in sound processing for prosthetic hearing devices, thereby enriching the auditory experience for users.

Advantages of Quantum Computing: The unique characteristics of quantum computing, which enable the simultaneous processing of vast data sets through quantum superposition and entanglement, may yield faster and more effective algorithms for signal processing, particularly in intricate or large-scale applications. For example, the Quantum Fourier Transform could facilitate exceptionally efficient frequency analysis within a quantum-augmented prosthetic ear.

Superposition of Signals: Techniques derived from quantum computing, such as the Quantum Fourier Transform, could enable the processing of sound data as quantum states, thereby allowing for advanced and intricate manipulation of signals. In this context, sound waves could be processed via a quantum circuit, utilizing the superposition of various frequencies to extract valuable insights and enhance the auditory experience.
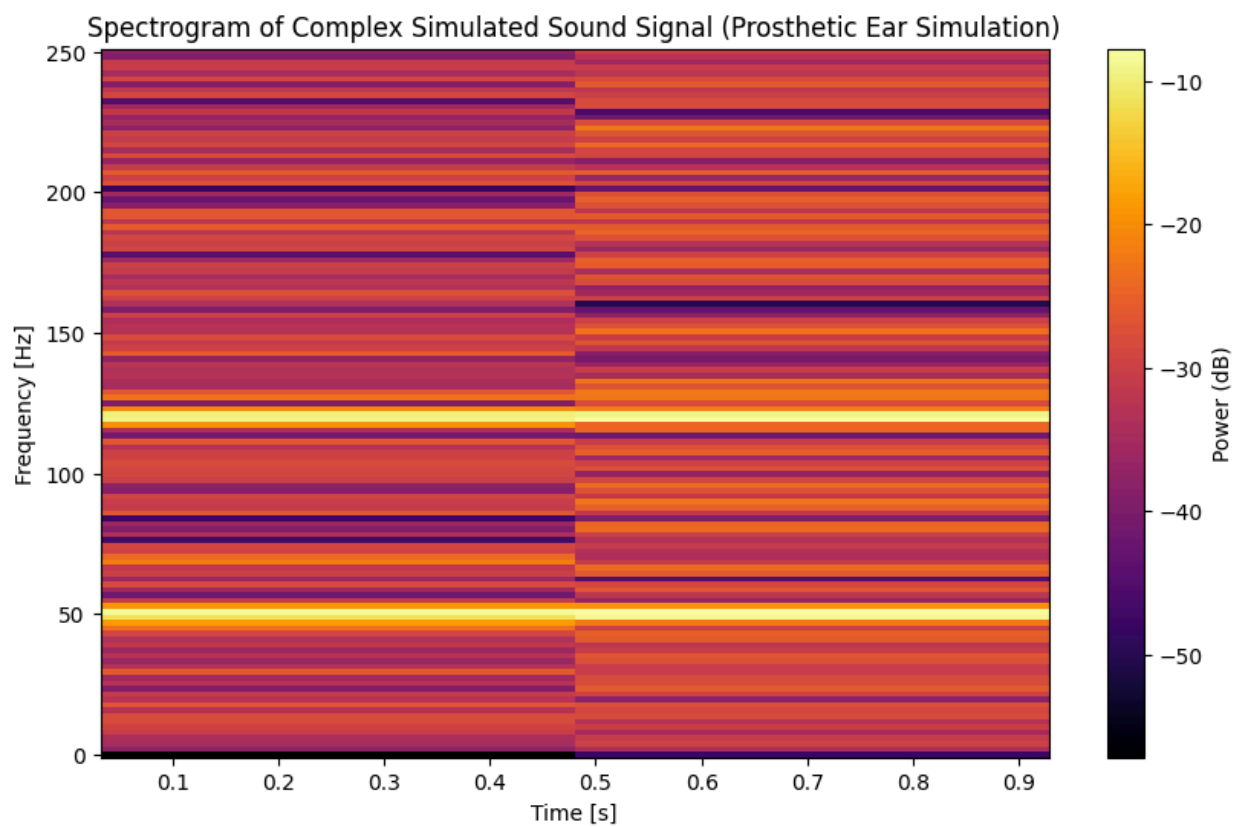
Graph 1: Spectrogram visualization - Quantum Signal Processing & Sound Simulation
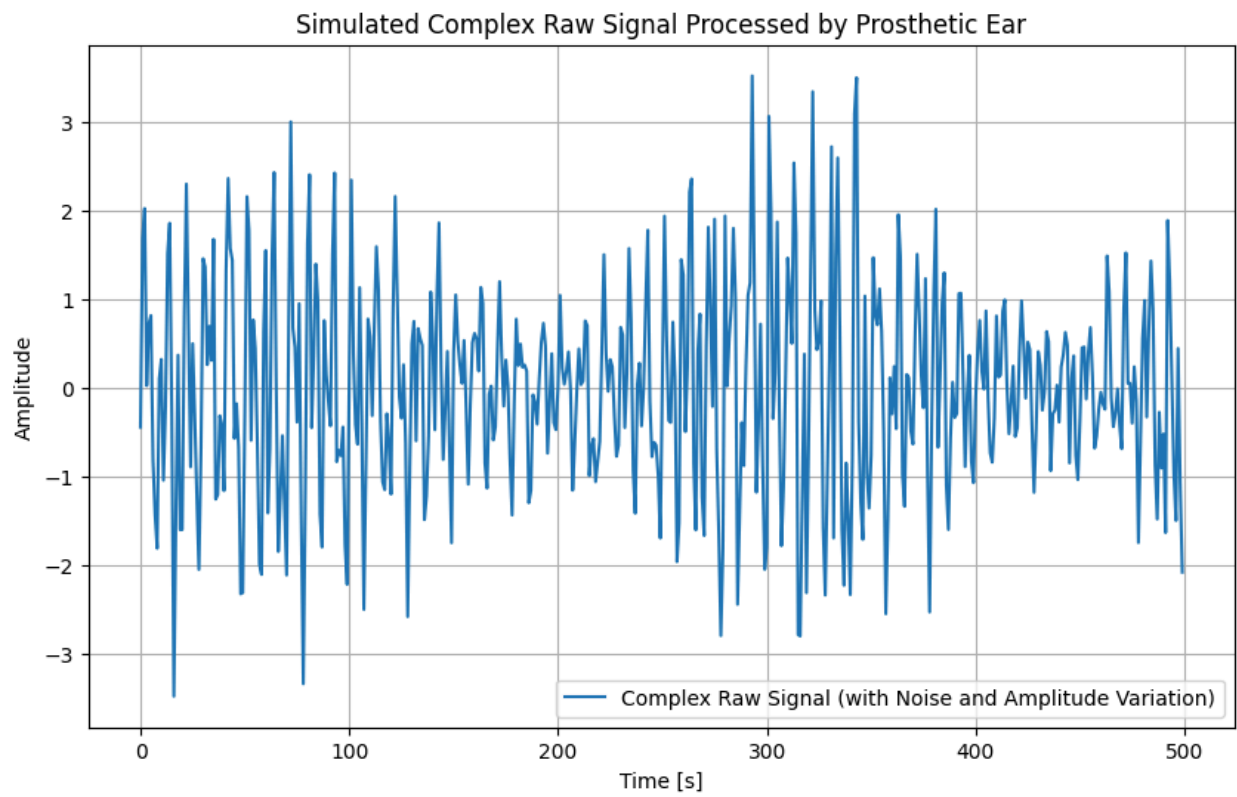
Graph 2: Quantum Signal Processing Simulation
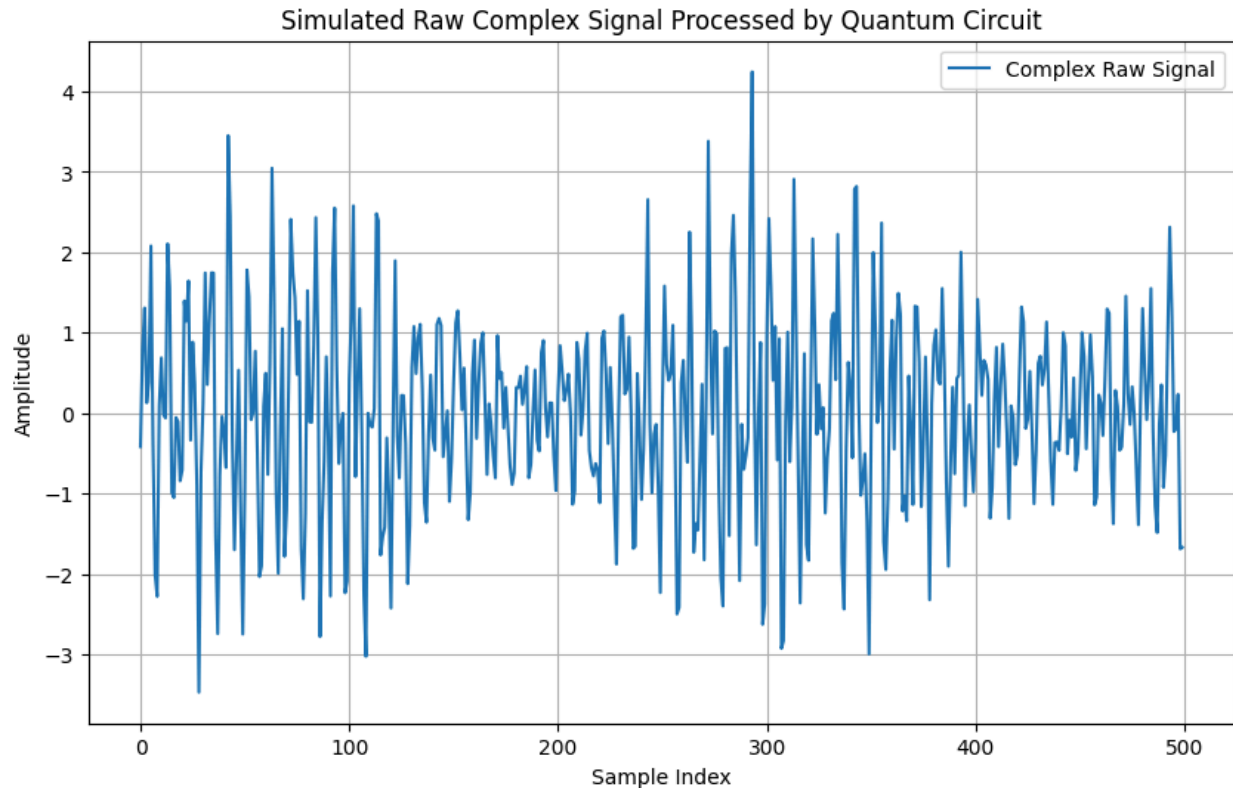
Graph 3: Advanced Quantum Classifier - Quantum Signal Processing & Sound Simulation

Graph Interpretation:

Spectrogram Visualization:

The simulation of sound is achieved by combining two sine waves at distinct frequencies, which exemplifies a basic sound signal, such as a musical note or spoken language. The function scipy.signal.spectrogram is employed to create a visual depiction of the sound in the form of a spectrogram. This spectrogram illustrates the variations in the signal's frequency content over time, mirroring the analytical capabilities of a prosthetic ear as it processes sound data. The resulting plot features the spectrogram along with a color bar that denotes the power levels in decibels (dB).

Quantum Signal Processing Simulation:

A quantum classifier is established using Qiskit to analyze a straightforward dataset. This serves as a metaphor for how a prosthetic ear might leverage quantum computing to categorize sound signals or adjust to the specific auditory

requirements of the user. The raw signal is visualized, demonstrating its potential processing through quantum circuits in a more intricate configuration.

Advanced Quantum Classifier:
The application of more sophisticated quantum gates, such as Hadamard and CNOT, is utilized to emulate a more advanced classification mechanism. This illustrates the potential of quantum computers to enhance signal processing for prosthetic devices, resulting in quicker and more precise classifications.

Classical Fourier Transform (FFT) for Prosthetic Ear:

Visualization of Prosthetic Ear with Fast Fourier Transform (FFT)
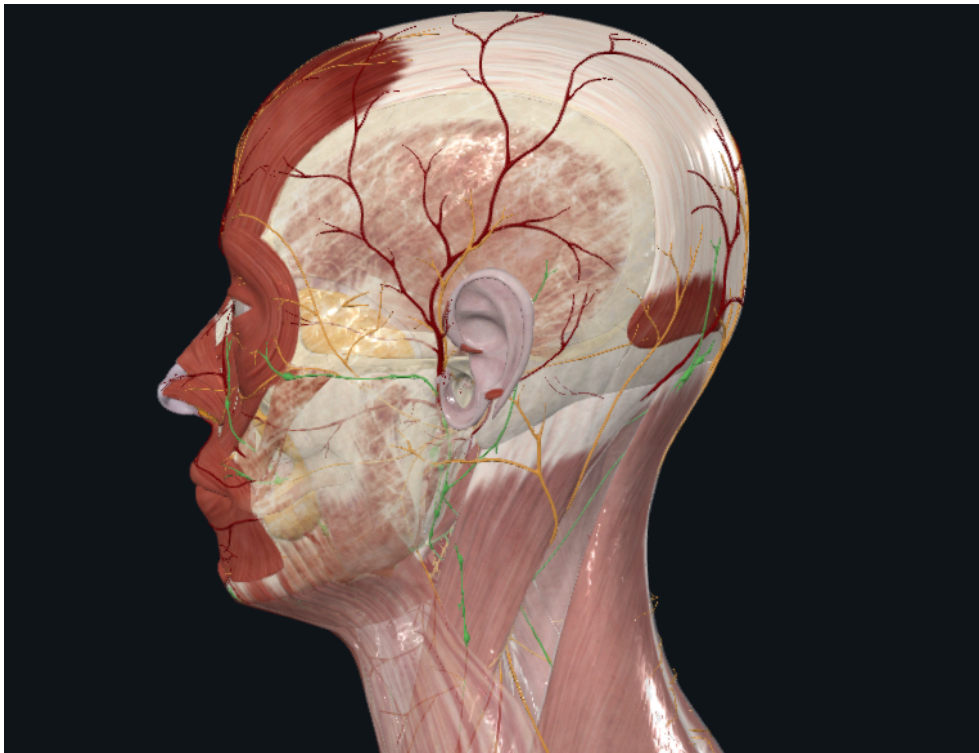

Image 1: Classical FFT (green) operating within the prosthetic ear. To better visualize the FFT, this image was generated through the courtesy of Complete Anatomy and is used in accordance with proper protocol

This image highlights the **Fast Fourier Transform (FFT)** within a prosthetic ear, represented by the **green signal flow**. The FFT facilitates rapid, real-time processing of sound signals, enabling the prosthetic to analyze and adjust frequencies for immediate auditory feedback and clarity. The visualization adheres to **anatomical protocols** and **scientific standards**, ensuring an accurate and precise representation of how FFT enhances sound processing in the prosthetic ear.
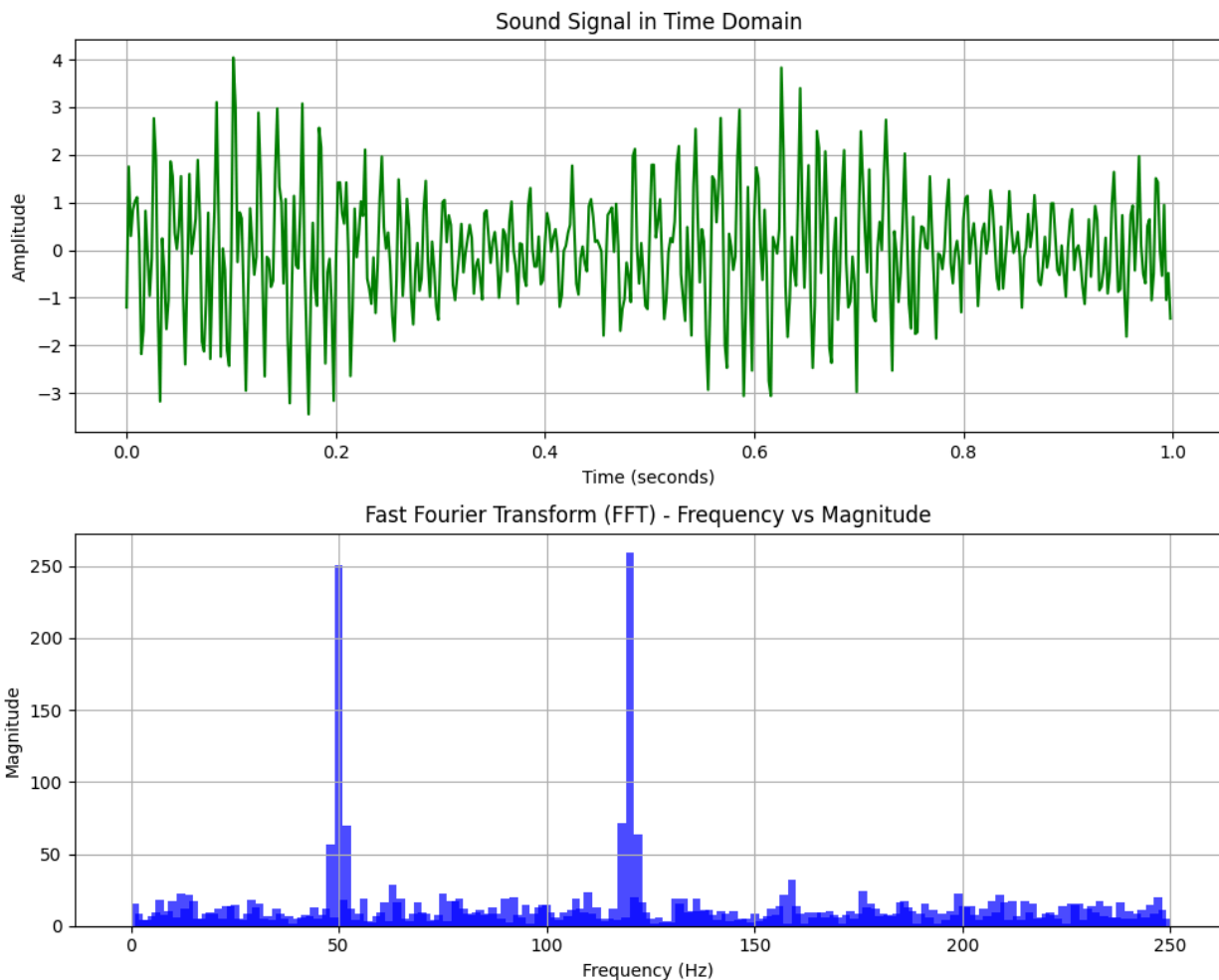
Graph 4: FFT on Simulated Sound Signal

● **Frequency Decomposition:** The classical Fast Fourier Transform (FFT) serves as a tool for breaking down sound signals into their individual frequency components. Given that sound signals are composed of multiple frequencies, the FFT enables the prosthetic device to assess the energy levels present within each frequency band.

For instance, when an individual speaks or listens to music, the FFT can disassemble the sound into its fundamental frequencies, thereby allowing the prosthetic ear to selectively filter, amplify, or diminish specific frequencies based on the user's hearing loss characteristics.

- **Signal Enhancement:** Subsequently, the hearing device can utilize the information obtained from the frequency domain to amplify desired frequencies, such as those associated with speech, while simultaneously minimizing background noise, which may include low-frequency hums or high-pitched ringing.

- **Noise Reduction:** The prosthetic ear can utilize the outcomes of the FFT to identify frequencies linked to unwanted noise and implement algorithms to eliminate them, ensuring that the user perceives only the essential sounds. In the context of speech processing within hearing aids, the device may concentrate on enhancing the frequency range that corresponds to human speech, typically between 250 Hz and 4 kHz, while attenuating low-frequency noise.

The Relationship Between the Quantum Fourier Transform (QFT) and Prosthetic Ear Simulations:

Frequency Analysis: The QFT serves as a tool for examining the frequency components within a signal. Classical prosthetic ears utilize techniques such as the Fast Fourier Transform (FFT) to decompose complex auditory signals into their individual frequency elements. The quantum methodology, represented by the QFT, presents an alternative avenue for sound signal processing that merits investigation.

Quantum Signal Processing: Implementing a QFT on an auditory signal allows for the examination of its frequency-domain representation. This capability is crucial for prosthetic ears, enabling the selective amplification or attenuation of specific frequencies tailored to the user's hearing impairment. Rather than relying solely on classical FFT techniques, exploring a quantum approach may yield more efficient or innovative methods for conducting this frequency analysis.

Enhancing Sound Processing: Within the quantum framework, following the application of the QFT, one could:

- Enhance specific frequencies where the user experiences hearing loss.
- Eliminate undesirable frequencies, such as background noise or those that trigger sensitivity issues.

The quantum states derived from the QFT can inform which segments of the sound signal require amplification or reduction. Through meticulous analysis of the quantum output, it becomes feasible to pinpoint dominant frequencies and leverage that data for subsequent processing.

Quantum Algorithms for Signal Enhancement: In addition to frequency analysis, quantum computing holds the promise of executing optimization algorithms that could:

- Improve sound quality by filtering out background noise or amplifying particular frequencies in a manner that adjusts to the user's changing auditory environment.
- Utilize quantum machine learning to progressively refine the signal processing capabilities of the prosthetic ear based on ongoing auditory inputs, thereby enhancing its adaptability to various sound environments over time.

Quantum Speedup and Efficiency: While classical techniques such as the Fast Fourier Transform (FFT) demonstrate high efficiency, quantum computing has the potential to accelerate specific signal processing tasks. Theoretically, quantum

algorithms, including the Quantum Fourier Transform (QFT), may enable more efficient signal processing for particular problem types, which could result in the development of more sophisticated prosthetic ear technologies. For instance, the implementation of quantum-enhanced signal filtering could yield benefits such as:

- Accelerated signal processing.
- Enhanced precision in frequency control.
- Real-time adaptive filtering informed by quantum-enhanced sound environment analysis.

Quantum Superposition and Entanglement: Within a quantum framework, sound signals are represented by quantum states that exist in superposition. This characteristic allows for the simultaneous processing of multiple signal representations, facilitating quicker and more adaptable management of intricate sound data. Consequently, this capability could enable prosthetic ears to respond to real-time variations in the acoustic environment more efficiently than traditional systems.

Visualization of Prosthetic Ear with Quantum Fourier Transform (QFT):
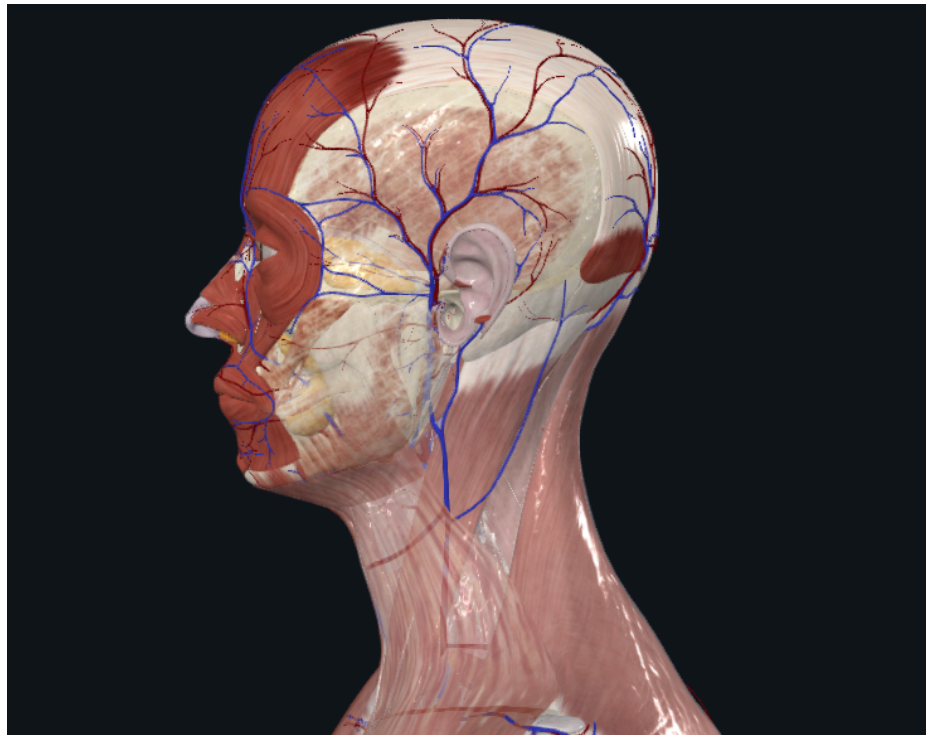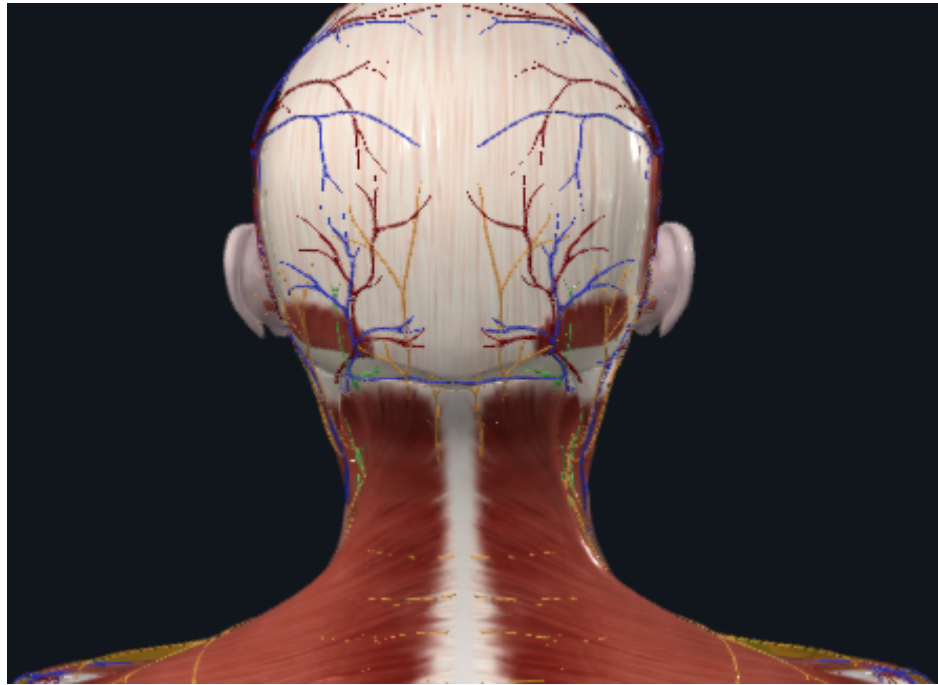
These images illustrate the **Quantum Fourier Transform (QFT)** within a prosthetic ear, represented by the **blue signal flow**. The QFT enables advanced quantum signal processing, allowing for efficient decomposition of sound data into its frequency components at a quantum level. This enhances the prosthetic's ability to handle complex sound signals with greater precision. The anatomical features and quantum processing pathways have been visualized according to established **anatomical and scientific guidelines**, ensuring accuracy and clarity in the depiction.

Simulated Complex Raw Signal Processed by Prosthetic Ear
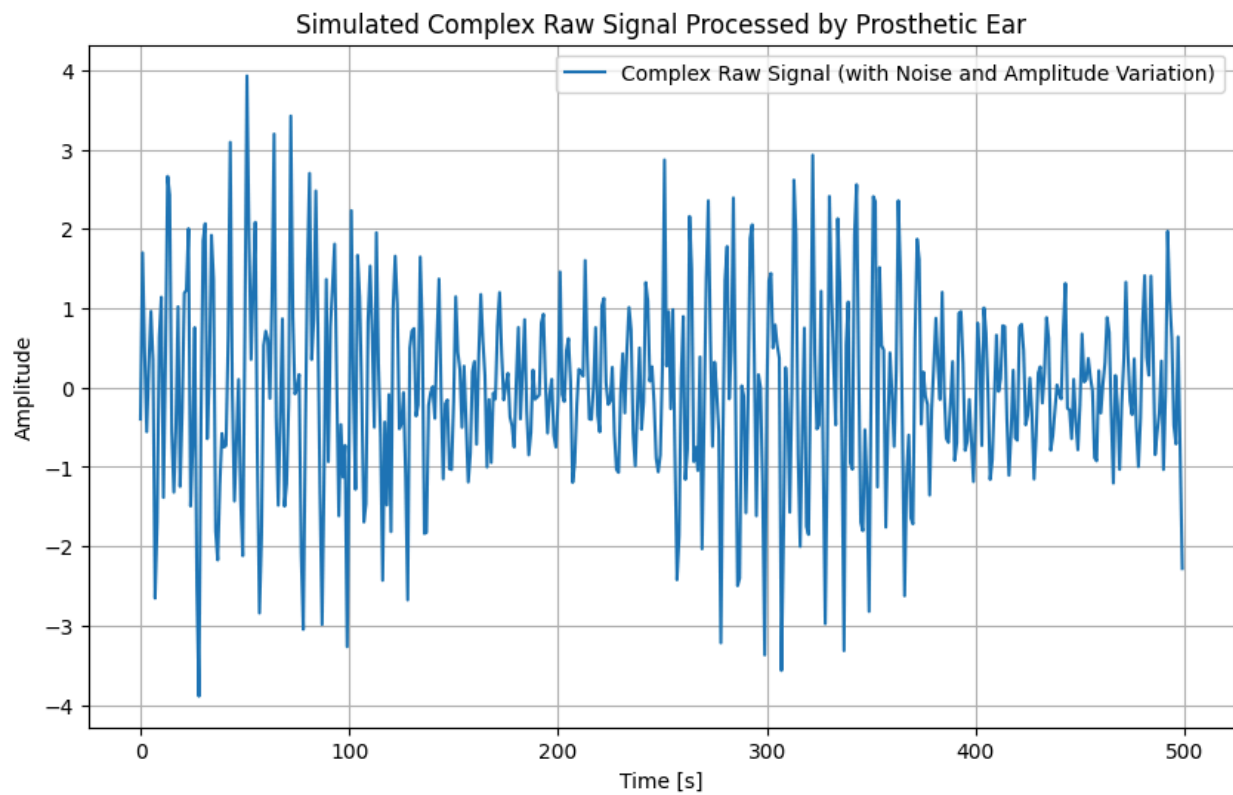
Graph 5: Simulating QFT on Complex Sound Signals

Quantum Fourier Transform Result (Measured Quantum States)
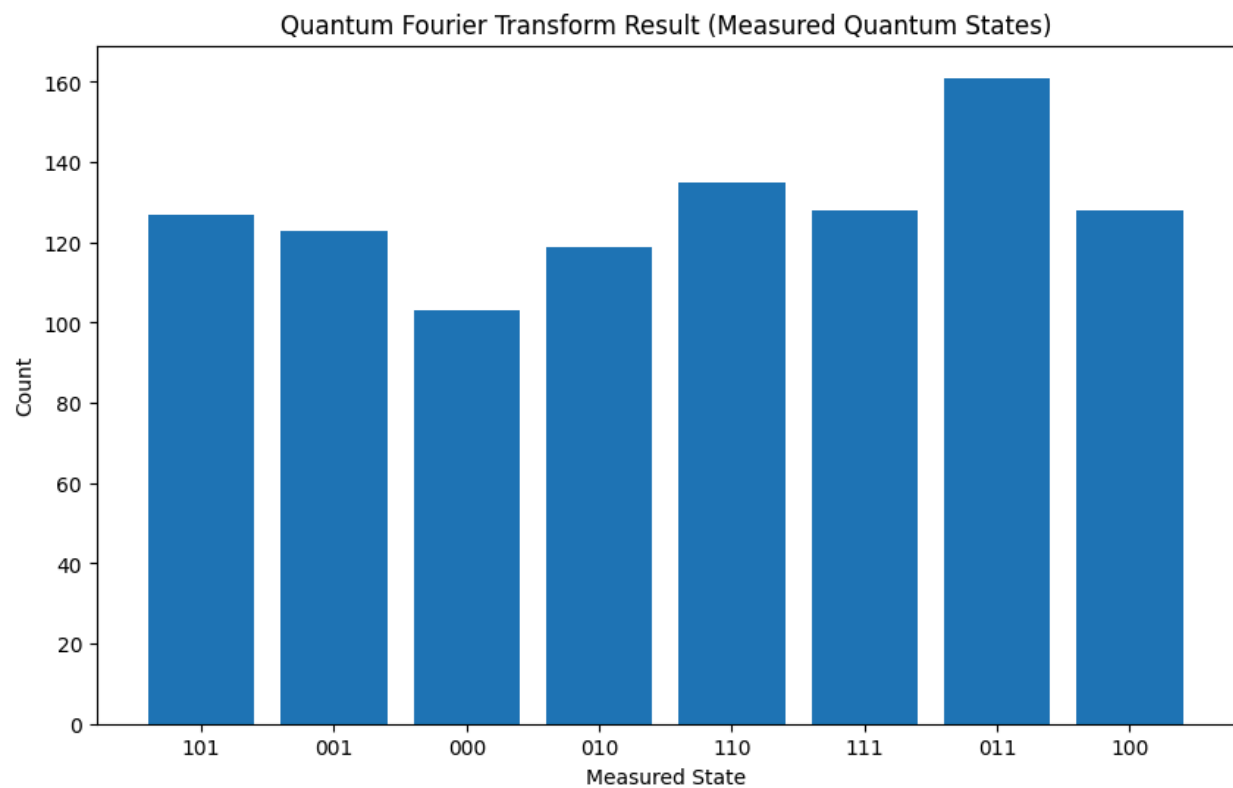
Graph Interpretation:

The Quantum Fourier Transform Counts: **{'101': 127, '001': 123, '000': 103, '010': 119, '110': 135, '111': 128, '011': 161, '100': 128}**, presents the measurement outcomes of the quantum state following the application of the Quantum Fourier Transform (QFT) to the signal.

The following points elucidate this output:

- **Measurement Results:** The provided dictionary illustrates the quantum measurement frequencies of various potential states (e.g., '101', '001', etc.). Each state signifies a possible quantum configuration post-QFT application. The frequency of each state (e.g., 127 for state '101') reflects how often that particular quantum state was recorded during the execution of the quantum circuit.
- **Binary States:** Each binary representation (e.g., '101', '000', etc.) denotes a distinct quantum state within a qubit register. These states emerge from the principles of superposition and quantum entanglement facilitated by the QFT.

Interpretation of the Results: The QFT transforms classical signals into quantum states. The frequency associated with each quantum state (the count) can be viewed as a representation of a frequency component of the original signal, albeit this interpretation is somewhat abstract and lacks a direct correlation to conventional frequency-domain analysis, such as Fourier's continuous or discrete transforms.

This probabilistic output could theoretically serve several purposes:

- **Identification of Dominant Frequencies:** Similar to how the Fast Fourier Transform (FFT) identifies prominent frequencies within a signal, the Quantum Fourier Transform (QFT) may assist in determining the frequencies present in a quantum state, offering valuable insights into which frequency bands are essential for amplification.

- **Data Compression:** Quantum signal processing has the potential to enable more efficient data representation, which could be advantageous for prosthetic ear devices that require rapid processing of substantial audio data. The QFT may facilitate these devices in managing data effectively by retaining only the most pertinent frequency information.

- **Noise Filtering in the Quantum Domain:** Quantum algorithms could be employed to implement sophisticated noise filtering techniques utilizing the QFT. These algorithms may effectively distinguish noise components from significant frequencies, thereby enhancing the ability of hearing aids to concentrate on critical sounds, such as speech.

A Practical Illustration of a Prosthetic Ear:

Consider a prosthetic ear equipped with a quantum-based processor:

Step 1: The device's microphone captures sound, such as spoken words or ambient noise.

Step 2: This sound is transformed into quantum states through a quantum encoding method.

Step 3: The Quantum Fourier Transform (QFT) is utilized to examine the frequencies within the quantum framework.

Step 4: Utilizing the outcomes from the QFT, the prosthetic ear modifies the sound by amplifying absent frequencies or eliminating undesirable noise.

Step 5: The modified audio signal is delivered to the user, thereby improving their auditory experience.

Combining Quantum and Classical Fourier Transforms:

Visualization of Prosthetic Ear with Quantum Fourier Transform (QFT) and Fast Fourier Transform (FFT) Integration:
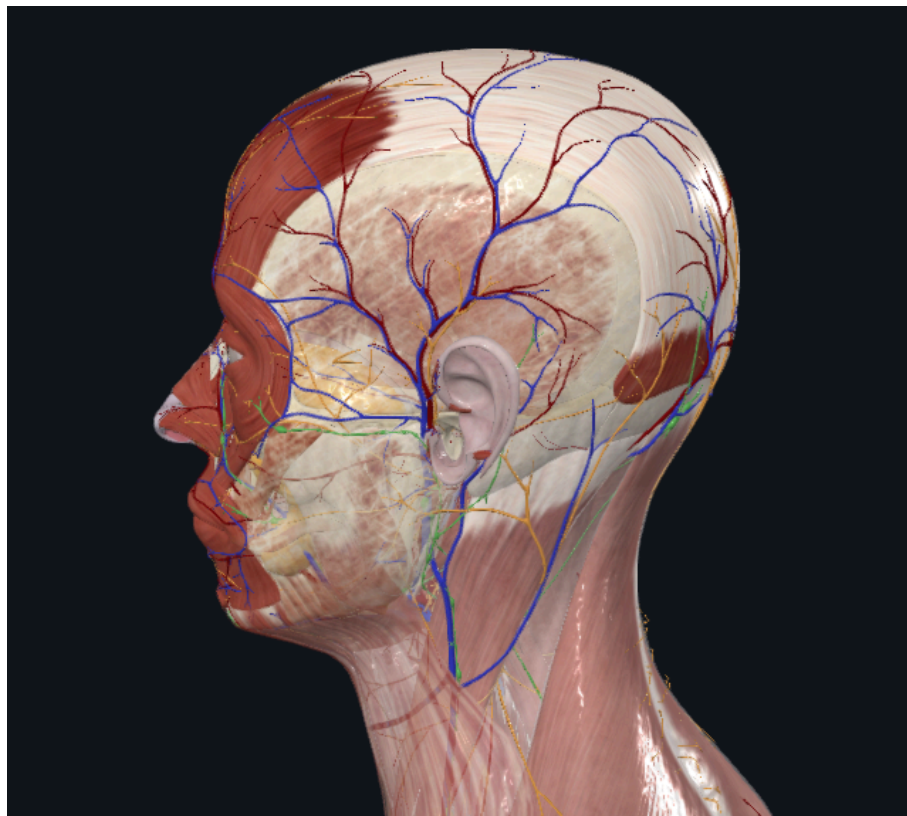

Image 4: Integration of QFT (blue) and FFT (green) operating within the prosthetic ear. To better visualize the QFT and FFT integration, this image was generated through the courtesy of Complete Anatomy and is used in accordance with proper protocol

This image presents a detailed anatomical visualization showcasing a prosthetic ear enhanced with both **Quantum Fourier Transform (QFT)** and **Fast Fourier Transform (FFT)** technologies. The **blue signal flow** represents the dynamic processing of sound signals through quantum and classical pathways, symbolizing the advanced auditory system in action. The integration of QFT allows for quantum-enhanced signal analysis, while FFT, the **green signal flow**, ensures rapid real-time processing. All anatomical features and processing pathways have been depicted following established **anatomical protocols** and **scientific visualization guidelines** to ensure accuracy and clarity.

In the realm of prosthetic ear technology, the integration of classical Fast Fourier Transform (FFT) and quantum Fourier Transform (QFT) may be conceptualized as follows:

Classical FFT for Immediate Processing: The prosthetic ear would predominantly employ classical FFT to conduct real-time frequency analysis and sound data filtering. This approach is favored due to the speed and efficiency of classical FFT in managing standard auditory functions, such as minimizing background noise, enhancing vocal clarity, and tuning into specific frequencies of interest.

Quantum QFT for Advanced Analysis and Optimization: Concurrently, QFT could be utilized for more intricate tasks in the background. After the initial sound processing via classical FFT, a quantum computer could be engaged to:

- **Examine the processed data:** Implement quantum algorithms to uncover patterns, identify anomalies, or execute high-dimensional signal processing that may pose challenges for classical systems.
- **Enhance the hearing algorithm:** Quantum optimization techniques could refine the signal processing workflow, enabling the prosthetic ear to adaptively filter noise or concentrate on speech, thereby adjusting to the user's auditory environment over time.

Hybrid Model: Future iterations of prosthetic ears may feature a hybrid architecture, wherein classical techniques are employed for real-time, low-latency

processing—essential for effective hearing—while quantum computing is reserved for sophisticated analysis, optimization, and learning. For instance:

- Utilizing classical FFT to extract sound frequencies.
- Employing quantum QFT to enhance the hearing aid's responsiveness in real-time or to analyze extensive datasets that may reveal trends in the auditory environment, such as distinguishing between noise and speech or monitoring environmental changes.

Practical Example

Consider a scenario involving a prosthetic ear situated in a loud setting, such as a bustling concert. The traditional Fast Fourier Transform (FFT) would conduct real-time frequency analysis to distinguish speech frequencies from ambient noise, thereby enhancing the clarity of speech. Concurrently, a quantum processor could employ Quantum Fourier Transform (QFT) to refine the ear's functionality by examining sound patterns and modifying the real-time filtering algorithms based on insights derived from quantum-enhanced data analysis.

This integrated approach could potentially alleviate the computational load on classical processors, enabling the implementation of more sophisticated filtering, noise-canceling, and adaptive learning systems, ultimately resulting in a more efficient prosthetic ear.

Step 1: Sound Acquisition

The prosthetic ear utilizes microphones to capture sound.

Step 2: Classical FFT Processing

The captured sound signal undergoes real-time processing through classical Fast Fourier Transform (FFT) to discern its frequency components, including speech frequencies and background noise. This technique aids in isolating pertinent frequency ranges while minimizing background noise or enhancing speech frequencies.

Step 3: Quantum QFT Analysis (Future Prospects)

Simultaneously, a quantum computer could analyze intricate data from the prosthetic ear. For instance, it could:

- Detect sound patterns that may elude classical analysis, such as specific background noises.
- Offer enhanced frequency analysis, contributing to improved filtering and adaptive features of the hearing aid.
- Potentially implement Quantum Machine Learning (QML) algorithms to continuously adapt and refine the ear's performance based on user feedback, thereby optimizing the overall user experience over time.

Step 4: Feedback Loop (Hybrid Method)

The QFT may enhance the filtering algorithms employed in the hearing aid, enabling it to adjust results based on complex data patterns. While classical FFT manages real-time processing, QFT addresses more intricate background tasks and optimization.

Further Investigations:

The following are future investigations that I am particularly interested in pursuing:

- Quantum Machine Learning utilized in prosthetic ears, enabling the device to learn from the user's preferences and evolve accordingly over time.

- Simulating quantum advancements in real-time audio processing for prosthetic auditory devices.

Conclusion:

In conclusion, although the Classical FFT remains a widely recognized method employed in contemporary hearing aids and prosthetic ears for the analysis and processing of sound signals, the Quantum Fourier Transform (QFT) presents opportunities for enhanced, probabilistic, and parallel signal processing in the future. This advancement could result in more adaptable, accurate, and efficient prosthetic ears; however, the direct implementation of QFT in prosthetics remains theoretical and is currently a subject of ongoing investigation.

REFERENCES

Cambridge, U. of (no date) *Quantum Fourier Transform & Quantum Phase Estimation*.
Available at:
https://www.cl.cam.ac.uk/teaching/1920/QuantComp/Quantum_Computing_Lecture_9.pdf

Cruz, R.L.J. *et al.* (2020) *An advanced prosthetic manufacturing framework for economic
personalised ear prostheses*, *Nature News*. Available at:
https://www.nature.com/articles/s41598-020-67945-z

Herkbert, P. (1998) *Fourier transforms and the fast fourier transform (FFT) ...* Available at:
https://www.cs.cmu.edu/afs/andrew/scs/cs/15-463/2001/pub/www/notes/fourier/fourier.pdf

NTi, A. (no date) *Home en*, *FFT*. Available at:
https://www.nti-audio.com/en/support/know-how/fast-fourier-transform-fft

Yang, Y. and Jin, F. (no date) *Quantum Fourier transform*, *Quantum Fourier Transform - an
overview | ScienceDirect Topics*. Available at:
https://www.sciencedirect.com/topics/computer-science/quantum-fourier-transform