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A Systematic Review of Transform in Biomedical Signals.

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Abstract
The Fourier transform is a widely used method of analysis in many contemporary scientific problems. The analysis of linear time-invariant systems is perhaps the most well-known use of this mathematical method. However, the Fourier transform is stressed as a general problem-solving tool. Its significance stems from the fact that each given connection may be seen from a totally new angle. The solution to many problems may be found by simultaneously imagining a function and its Fourier transform. Fourier transform (FT) is used to analyze the behavior of biomedical signals in frequency domain. In Matlab FFT command can be used to get the frequency domain signal. The Fourier transform is a fundamental tool in the decomposition of a complicated signal, allowing us to see clearly the frequency and amplitude components hidden within. In the process of generating an MR image, the Fourier transform resolves the frequency- and phase-encoded MR signals that compose k-space. Biomedical signals like electrocardiogram (ECG), photoplethysmographic (PPG) and blood pressure were very low frequency signals and need to be processed for further diagnosis and clinical monitoring. Transforms like Fourier transform (FT) and Wavelet transform (WT) were extensively used in literature for processing and analysis. Fourier and wavelet transforms were utilized to reduce motion artifacts from PPG signals so as to produce correct blood oxygen saturation (SpO2) values. In an important contribution we utilized FT for generation of reference signal for adaptive filter-based motion artifact reduction eliminating additional sensor for acquisition of reference signal. Similarly, we utilized the transforms for other biomedical signals. [13]

Keywords: *Fourier transform, biomedical signals, electrocardiogram signal, photoplethysmographic signal, wavelet transform, Fourier Transform Spectroscopy, Magnetic resonance imaging (MRI)*

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I. Introduction

The Fourier transform (FT) is a common analytical technique in the fields of medicine, wireless communications, signal processing, and image analysis due of its frequency-domain signal conversion capabilities. Many studies report the use of this instrument for frequency domain analysis of various biological data, including electrocardiograms, photoplethysmograms, and blood pressure readings. Following the success of FT, more transforms were created to assess and build new applications. The FT is a mathematical technique used for analyzing stationary signals, whereas the WT may be used to both stationary and non-stationary data. Numerous engineering disciplines make extensive use of the discrete wavelet transform (DWT).

Understanding and analyzing images is challenging. Digital image processing has several uses in the medical field. The most common ones are a CT or MRI scan and a magnetic resonance imaging (MRI) study. Digital image processing and analysis have many uses outside of medicine, remote sensing, natural resource survey and management, criminology, astronomy, meteorology, artillery, and office and industrial automation. Since vision is the most developed of the human senses, it stands to reason that visual representations play the most crucial role in human understanding. In order to analyze them properly, two-dimensional images of the same subject taken at different times, from different geometric angles, or with a different image sensor all need to be registered. The first stage in analyzing and fusing pictures is image registration. The reference and sensed pictures are aligned geometrically. Image analysis activities including picture fusion, change detection, and multichannel image restoration all require combining data from several sources into a single coherent picture, making image registration must.

II. Applications of Transforms in Biomedical Signals

The Fourier transform is essential to all contemporary imaging, but MRIs require it most. The complex periodic signal composed of numerous constituent frequencies is received by the detector (the detector array in CT, the piezoelectric disc in ultrasound, and the receiver coils in MRI). Rapid identification of some yeast and dermatophytes isolated from superficial fungal diseases can be achieved by the use of Fourier transform infrared spectroscopy. Many domains, including contemporary acoustics, voice communication, sonar, earthquakes, nuclear research, and even biomedical engineering, rely heavily on Fourier transform. In today's world, Fourier analysis is an essential tool for systems and signal analysis. In order to clearly detect the frequency and amplitude components that are concealed within a complex signal, the Fourier transform is an essential tool. The frequency and phase encoded MR signals that make up k-space are resolved by the Fourier transform during the creation of an MR image. We observe the MR image of the 2D inverse Fourier transform of k-space. Comprehending the Fourier transform is crucial for comprehending various magnetic resonance artifacts and the diverse data gathering techniques utilized in modern practice.

The Fourier transform has long been shown to be incredibly helpful in spectroscopic applications across all research domains requiring high wavelength accuracy, broad tunability, and high resolution. These spectroscopic techniques that make use of the Fourier transform are referred to as FTS. FTS is a well-known spectroscopic technique in which interferograms are gathered based on measurements of an electromagnetic radiation source's coherence in the space or time domain and then transformed into the frequency domain using Fourier transform.

Because of its nonperturbative and extremely sensitive characteristics, Fourier transform infrared spectroscopy is a fundamental and dependable method with a wide range of possible beneficial applications in the fields of biology and medicine. The wavelength of the light absorbed by the probe at specific vibration frequencies is examined using the FTIR spectroscopic approach. This approach produces a unique spectrum for biological material exposed to radiation; it is referred to as a molecular fingerprint. For food safety and quality in a processing, retail, or production setting, quickly and easily identifying microorganisms is essential. Traditional approaches such as serological testing, biochemical testing, and conventional plating involve multiple steps and may need a considerable amount of time to produce confirmed results.

The integration of Fourier transform spectroscopy techniques with nanotechnology, biology, and medicine presents novel prospects for atom and molecular detection and manipulation using nanodevices, potentially yielding a wide range of cellular biological and medicinal uses.

The inner ear signal is already divided into frequency segments, with each nerve signifying the detection of sounds in a certain restricted frequency range. Because the information is already divided into frequencies, the brain does not need to do a Fourier transform. Radiology uses the Fourier transform extensively, as it is a basic mathematical tool for signal analysis and is essential to the creation of contemporary MR images. Fourier transform spectroscopy (FTS) has emerged as a cutting-edge, robust, and ultrasensitive tool for investigating a wide range of physiologically significant systems, from single molecules to complex samples like live cells and tissues. Radiology uses the Fourier Transform extensively, as it is a basic mathematical tool for signal analysis and is essential to the creation of contemporary MR images. A fundamental comprehension of the functions of the Fourier transform is necessary to comprehend MRI procedures.

III. Fourier transform spectroscopy (FTS) and its biomedical applications.

Fourier transform spectroscopy (FTS) has emerged as a cutting-edge, robust, and ultrasensitive tool for investigating a wide range of physiologically significant systems, from single molecules to complex samples like live cells and tissues. These contemporary, improved spectroscopic techniques are a vital area of study that may be put to use in many different scientific and industrial contexts. The primary objective is to discuss the most current findings about the FTS technology and its many medical, biological, and biomedical applications.

The fundamental concepts of the FT theory are quickly revisited after a brief overview of the development of the significant discoveries in the area of Fourier transforms. New spectrum applications in medical, biological, and biomedical fields are discussed here to demonstrate the versatility of Fourier transforms.

Fourier transform spectroscopy, including FT-VIS, FT-IR-ATR, FT-IR-PAS, FT-IR-Imaging, and FT-IR-Cyclotron Resonance Energy Transfer are some of the methodologies used in spectroscopy.

IV. Use of Transforms for ECG Signals.

Electrocardiograms (ECG) are extensively used for the diagnosis of cardiac arrhythmias. A transform is a mathematical tool that moves from the time domain to the frequency domain. The transformation changes the representation of the signal by projecting the signal onto a set of essential functions but does not change the information content of the signal. Various types of feature extraction methods have been available for decades, including FFT, DFT, Short-Time Fourier transform (STFT) and wavelet-based features of, features based on crossed wavelets. The Fast Fourier Transform removes low frequencies from the ECG signal. The inverse fast Fourier transform is used to remove noise. The Fast Fourier Transform is used to transform the input signal from the dataset after it has been preprocessed by removing nulls. FFT is used to convert the time domain signal to frequency domain ECG signal for more accurate peak extraction.

The Fast Fourier transform is well known method, which is used for converting time domain signal in to frequency domain to obtain frequency coefficients. The FFT is used to identifying QRS complex peak (R) in ECG signal and further arrhythmia classification was done by using neural network [10]

$X = \sum_{n=0}^{N-1} xne^{\frac{-2\pi i}{N}} nk$ Where k = 0…, N-1 (1)

The wavelet transform allows the user to analyze the data in two dimensions, time and frequency domain simultaneously. The wavelet transform provides the different scale with different resolutions of ECG signal in both frequency and time representation. The discrete wavelet transform (DWT) is used for detection of QRS complex and arrhythmia [11]. This transform is use to detect heart rate with better accuracy as compare with the other transform techniques. The arrhythmia, disorder and other abnormalities of heart can be detected on the basis of ECG morphology [12]. The wavelet transform equation for signal x(t) is defined by eq. (2)[11]:

$Wax(b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t)\Psi\left(\frac{t-b}{a}\right) dt$ (2)

Where ɑ is the scaling, b= translation parameter

V. Comparative study of various transform.

The comparative study of various transform techniques for biomedical signal gives an idea about the advancement in biomedical field. The transform techniques like FFT, WT, Laplace Transform, Hilbert Transform and Hadamard Transform were used in biomedical signal analysis. The WT has become one of the emerging tool for time and feature analysis of ECG and EEG data. The WT has ability to extract the related component of the signal using variety of wavelet-based techniques as far better than the traditional Fourier transform methods. The laplace transform basically used to detect the ischemia event in ECG signal. The advantage of Hilbert Transform is that it changes the phase value without changing the spectral component of the amplitude. The Hadamard Transform is well known for low memory requirement and less computational complexity. The EEG is a non-stationary and nonlinear signal, which doesn't fallow any fix pattern. The continuous wavelet transform (CWT) has ability to perform efficient analysis of non-stationary signal over a wide range of applications. The CWT allows arbitrary high resolution of signal in time frequency domain. Normally CWT based algorithms used for identification of epileptic seizure in EEG data.

The above table mainly shows the utility of transform for the analysis of ECG signal using various transform techniques but few transform techniques among them are also suitable for EEG signal analysis like continuous WT, Hilbert transform, Hadamard transform. The average accuracy in feature identification of ECG signal is found highest in wavelet transform. The Hilbert transform and Hadamard transform give good accuracy in feature identification and also capable of detecting atrial fibrillation, QRS complex in weak ECG signal.

TABLE I
Comparative study of various transform

Transforms	Purpose of Study	Accuracy	Limitations
Fast Fourier Transforms.	1. R-Peak detection in ECG signal 2. S Peak detection in ECG 3. Heart Rate computation	98.48 % (Feature Identification)	Artificial neural network data set required for training
Wavelet Transforms.	1. Arrhythmia classification of ECG signal 2. QRS- complex detection 3. Motion artifacts removal of ECG signal	99.92 % (Beat Detection)	Not quantified
Laplacian based-Karhunen-Loeve transform.	1. Ischemic event detection	Improved accuracy	Single investigation
Hilbert Transform.	1. QRS Detection 2. Weak ECG signal Detection	Average detection accuracy of 99.80	Not Quantified
Hadamard Transform	1. Atrial Fibrillation detection	99.3% (With LMNN classifier)	Not Quantified

VI. Challenges and Constraints.

The challenges in biomedical signal processing include hardware constraints and capturing high-quality signals. The opportunities include using multi-modal signal processing to improve performance. The Fourier Transform is limited to analyzing signals that are continuous in time, so it cannot be used to analyze signals that are discrete in time. It is sensitive to noise, so signals with high levels of noise may not be accurately represented by the Fourier Transform. The Fourier Transform plays a critical role in a broad range of image processing applications, including enhancement, analysis, restoration and compression.

VII. Conclusion

The exploration of mathematical expressions in Fourier transform-based analysis of biomedical signals offers a profound understanding of the intricate connection between mathematics and medical diagnostics. The journey through this study has illuminated the pivotal role that mathematical concepts play in unraveling the complexities hidden within biomedical signals, contributing to the enhancement of healthcare and our comprehension of the human body's inner workings.

The utilization of Fourier transform, as guided by mathematical expressions, has unveiled a remarkable bridge between time-domain signals and their frequency-domain counterparts. This transformation not only reveals distinct frequency components but also provides a valuable perspective on the physiological phenomena underlying these signals. Through meticulous analysis, we have deciphered the significance of peaks, troughs, and patterns in the frequency domain representation, forging a path to the interpretation of clinical insights.

The synergy between mathematics and biomedical sciences has yielded multifaceted benefits. Accurate diagnoses, personalized treatment strategies, and innovations in medical device design emerge as tangible outcomes of this integration. The ability to translate complex signal information into a visual and quantifiable format empowers medical professionals to make informed decisions, while also offering a foundation for groundbreaking research and exploration.

Yet, this journey is not without its challenges and ongoing quests. The ever-evolving landscape of biomedical sciences demands a continuous refinement of mathematical expressions, signal processing techniques, and their application. Collaborations between mathematicians, engineers, and medical experts remain crucial for pushing the boundaries of knowledge and technology, leading to more precise diagnostic tools and improved patient care.

In essence, the study of mathematical expressions in Fourier transform-based analysis of biomedical signals has transcended the realm of theoretical equations to forge a link between mathematical rigor and tangible medical advancements. This connection breathes life into numerical expressions, transforming them into agents of progress and discovery in the realm of human health. As we conclude this exploration, we recognize that the journey is far from over. The path illuminated by mathematical expressions continues to guide us towards a future where the synergy of mathematics and medicine enriches lives, fosters innovation, and propels our understanding of the intricate tapestry of human health.

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