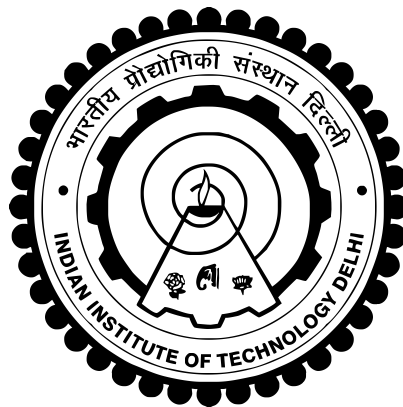


**SOME STUDIES ON ANALYTIC SIGNAL
MATCHED FILTER BANK WITH
APPLICATIONS**

GEETANJALI SRIVASTAVA



**DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
SEPTEMBER 2021**

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by

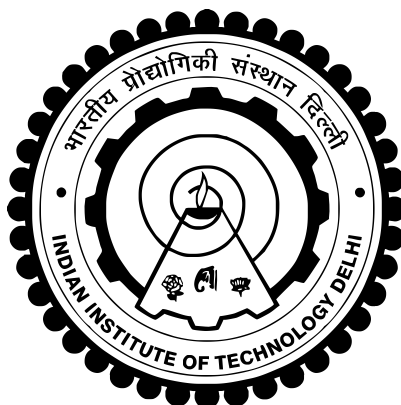
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DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

SEPTEMBER 2021

Dedicated to

My Family

&

Friends

Certificate

This is to certify that the thesis entitled “**Some studies on analytic signal matched filter bank with applications**” being submitted by **Ms. Geetanjali Srivastava** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is the record of the bona-fide research work carried out by her under my supervision. In my opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree. The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

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Department of Electrical Engineering

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Abstract

The main objective of this thesis is to propose a novel signal decomposition approach which is truly intrinsic and adaptive to the given input signal and is able to decompose instantaneous signals into non-overlapping bands using analytic signal matched filter bank. The analytic signal matched filter bank in consideration is a M-band uniformly decimated, multirate filter bank, obtained by combining the signal matched analysis filter bank and signal matched synthesis filter bank with analytic signals procedure. The proposed approach is utilized to decompose a signal for given statistics as well as given data case scenario. The adaptive nature of our algorithm enables us to track time varying signal characteristics and can be utilized for variety of signal processing and signal analysis applications including coding and denoising. We have demonstrated the application and efficacy of the proposed algorithm by denoising and performing TFA on sample from biomedical signal processing and speech signal processing.

It is easily seen that output of an LTI system, with random input, can be written as a superposition of damped exponentials having random amplitudes and phases. Hence we infer that if the system parameters are slowly varying with time then it manifest in terms of slowly varying coefficients and phases. Translated in terms of poles, they correspond to the natural frequencies of a system, the output, for a random input signal, vary in amplitude and phase around these frequencies. This forms the basis for our proposed signal decomposition scheme. Given any signal, that we wish to decompose, we assume that it is output of a system with random input. One of the most appropriate decomposition of this signal, which could throw light on the system as well as its input, would be in terms of a bank of bandpass filters around the natural frequencies. Since (i) the decomposition involves bank of filters, multi-rate filter-banks are natural choice for the purpose; (ii) the

analytic representation is the most convenient form for band pass signal representation we explore analytic form of multi-rate filter banks; (iii) our objective, as mentioned earlier, is to explore signal decomposition scheme which is purely intrinsic to the signal and also adaptive, designing the multi-rate filter bank in signal matched fashion, seemed a natural way to go; (iv) finally, the down sampling operation in the analysis side spreads the spectra in the entire band it is more logical to carry out orthogonalization/decoupling, across the channels, on the synthesis side rather than analysis side, if we want different channels to carry different band information. This fact is clearly highlighted by observing overlapping obtained in earlier proposed signal matched filter bank scheme[1] where the goal was to obtain optimum coding gain.

We have also defined a Hilbert space framework to provide a geometrical interpretation of the proposed algorithm. We present a time as well as order recursive, least squares algorithm for the proposed algorithm ASMFB for the given data case.

Further more, we demonstrate applications of our proposed algorithm for the analysis of real-time non-stationary signals. Since ECG signals are integral part of any scheme for diagnosis and analysis of heart diseases, we have applied ASMFB algorithm for real-time classification of abnormalities such as PVC in ECG data as it arrives. The proposed algorithm decomposes a given ECG signal into decorrelated non-overlapping bands, which follow AM-FM character such that each band has only one harmonic component of the original signal. The proposed method for classification of ECG signal, into normal and abnormal, is purely based on ASMFB algorithm for feature extraction and uses SVM as a classifier.

Experimental results on publicly available database demonstrate that the proposed feature sets effectively characterize the ECG signals and are suitable for classification between different classes of ECG abnormalities with a classification accuracy of 99%. We have also demonstrated efficacy of the proposed algorithm for pre-processing of these non-stationary ECG signals by removing artifacts and noises in the corrupted ECG signal.

The thesis also presents a spin-off arising from the developed theory. The non-linear dynamical system analysis of denoised ECG signal obtained after using proposed algorithm

has been presented. The proposed phase space analysis based technique has shown to be effective in detecting cardiac arrhythmia in critically ill patients and hence may aid in the diagnosis of heart disease in intensive care units.

सार

इस थीसिस का मुख्य उद्देश्य एक उपन्यास सिग्नल अपघटन दृष्टिकोण का प्रस्ताव करना है जो वास्तव में दिए गए इनपुट सिग्नल के लिए आंतरिक और अनुकूली है और विश्लेषणात्मक सिग्नल मिलान फ़िल्टर बैंक का उपयोग करके गैर-अतिव्यापी बैंड में तात्कालिक संकेतों को विघटित करने में सक्षम है। विश्लेषणात्मक सिग्नल मिलान फ़िल्टर बैंक विचाराधीन एक एम-बैंड समान रूप से विघटित, मल्टीरेट फ़िल्टर बैंक है, जो सिग्नल मिलान विश्लेषण फ़िल्टर बैंक और सिग्नल मिलान किए गए संश्लेषण फ़िल्टर बैंक को विश्लेषणात्मक सिग्नल प्रक्रिया के साथ जोड़कर प्राप्त किया जाता है। प्रस्तावित दृष्टिकोण का उपयोग दिए गए आँकड़ों के साथ-साथ दिए गए डेटा केस परिदृश्य के लिए एक संकेत को विघटित करने के लिए किया जाता है। हमारे एल्गोरिथ्म की अनुकूली प्रकृति हमें समय की बदलती सिग्नल विशेषताओं को ट्रैक करने में सक्षम बनाती है और इसका उपयोग विभिन्न प्रकार के सिग्नल प्रोसेसिंग और सिग्नल विश्लेषण अनुप्रयोगों के लिए किया जा सकता है जिसमें कोडिंग और डीनोइजिंग शामिल हैं। हमने बायोमेडिकल सिग्नल प्रोसेसिंग और स्पीच सिग्नल प्रोसेसिंग से नमूने पर टीएफए को निरूपित और निष्पादित करके प्रस्तावित एल्गोरिदम के अनुप्रयोग और प्रभावकारिता का प्रदर्शन किया है।

यह आसानी से देखा जा सकता है कि यादृच्छिक इनपुट के साथ एलटीआई प्रणाली के आउटपुट को यादृच्छिक आयाम और चरणों वाले नम घातांक के सुपरपोजिशन के रूप में लिखा जा सकता है।

इसलिए हम अनुमान लगाते हैं कि यदि सिस्टम पैरामीटर धीरे-धीरे समय के साथ बदल रहे हैं तो यह धीरे-धीरे अलग-अलग गुणांक और चरणों के रूप में प्रकट होता है। ध्रुवों के संदर्भ में अनुवादित, वे एक प्रणाली की प्राकृतिक आवृत्तियों के अनुरूप होते हैं, आउटपुट, एक यादृच्छिक इनपुट सिग्नल के लिए, इन आवृत्तियों के आसपास आयाम और चरण में भिन्न होता है। यह हमारी प्रस्तावित सिग्नल अपघटन योजना का आधार है। किसी भी संकेत को देखते हुए, जिसे हम विघटित करना चाहते हैं, हम मानते हैं कि यह यादृच्छिक इनपुट वाले सिस्टम का आउटपुट है। इस सिग्नल के सबसे उपयुक्त अपघटन में से एक, जो सिस्टम के साथ-साथ इसके इनपुट पर प्रकाश डाल सकता है, प्राकृतिक आवृत्तियों के आसपास बैंडपास फिल्टर के एक बैंक के संदर्भ में होगा। चूंकि (i) अपघटन में बैंक ऑफ़ फिल्टर शामिल हैं, बहु-दर फिल्टर-बैंक इस उद्देश्य के लिए स्वाभाविक पसंद हैं; (ii) विश्लेषणात्मक प्रतिनिधित्व बैंड पास सिग्नल प्रतिनिधित्व के लिए सबसे सुविधाजनक रूप है जिसे हम बहु-दर फिल्टर बैंकों के विश्लेषणात्मक रूप का पता लगाते हैं; (iii) हमारा उद्देश्य, जैसा कि पहले उल्लेख किया गया है, सिग्नल अपघटन योजना का पता लगाना है जो सिग्नल के लिए पूरी तरह से आंतरिक है और अनुकूली भी है, सिग्नल मिलान फैशन में मल्टी-रेट फिल्टर बैंक को डिजाइन करना, जाने का एक स्वाभाविक तरीका प्रतीत होता है; (iv) अंत में, विश्लेषण पक्ष में डाउन सैंपलिंग ऑपरेशन पूरे बैंड में स्पेक्ट्रा को फैलाता है, यदि हम अलग-अलग चैनल चाहते हैं, तो विश्लेषण पक्ष के बजाय संश्लेषण पक्ष पर, चैनलों के पार ऑर्थोगोनलाइज़ेशन/डिकॉडिंग करना अधिक तार्किक है। अलग बैंड जानकारी ले। इस तथ्य को स्पष्ट रूप से पहले प्रस्तावित सिग्नल मिलान फिल्टर बैंक योजना [1] में प्राप्त ओवरलैपिंग को देखकर स्पष्ट रूप से उजागर किया गया है जहां लक्ष्य इष्टतम कोडिंग लाभ प्राप्त करना था।

हमने प्रस्तावित एल्गोरिथम की ज्यामितीय व्याख्या प्रदान करने के लिए हिल्बर्ट अंतरिक्ष ढांचे को भी परिभाषित किया है। हम दिए गए डेटा मामले के लिए प्रस्तावित एल्गोरिथम के लिए एक समय के साथ-साथ पुनरावर्ती, कम से कम वर्ग एल्गोरिथम का आदेश देते हैं।

इसके अलावा, हम वास्तविक समय के गैर-स्थिर संकेतों के विश्लेषण के लिए हमारे प्रस्तावित एल्गोरिथम के अनुप्रयोगों को प्रदर्शित करते हैं। चूंकि ईसीजी सिग्नल हृदय रोगों के निदान और विश्लेषण के लिए किसी भी योजना का अभिन्न अंग हैं, इसलिए हमने ईसीजी डेटा में पीवीसी जैसी असामान्यताओं के वास्तविक समय वर्गीकरण के लिए एसएमएफबी एल्गोरिदम लागू किया है। प्रस्तावित एल्गोरिथम किसी दिए गए ईसीजी सिग्नल को अलंकृत गैर-अतिव्यापी बैंड में विघटित करता है, जो एएम-एफएम वर्ण का पालन करते हैं जैसे कि प्रत्येक बैंड में मूल सिग्नल का केवल एक हार्मोनिक घटक होता है। ईसीजी सिग्नल को सामान्य और असामान्य में वर्गीकृत करने के लिए प्रस्तावित विधि विशुद्ध रूप से फीचर निष्कर्षण के लिए एसएमएफबी एल्गोरिथम पर आधारित है और एसवीएम को क्लासिफायर के रूप में उपयोग करता है।

सार्वजनिक रूप से उपलब्ध डेटाबेस पर प्रायोगिक परिणाम प्रदर्शित करते हैं कि प्रस्तावित फीचर सेट ईसीजी संकेतों को प्रभावी ढंग से चिह्नित करते हैं और 99% की वर्गीकरण सटीकता के साथ ईसीजी असामान्यताओं के विभिन्न वर्गों के बीच वर्गीकरण के लिए उपयुक्त हैं। हमने भ्रष्ट ईसीजी सिग्नल में कलाकृतियों और शोर को हटाकर इन गैर-स्थिर ईसीजी संकेतों के पूर्व-प्रसंस्करण के लिए प्रस्तावित एल्गोरिदम की प्रभावकारिता का भी प्रदर्शन किया है।

थीसिस भी विकसित सिद्धांत से उत्पन्न एक स्पिन-ऑफ प्रस्तुत करता है। प्रस्तावित एल्गोरिथम का उपयोग करने के बाद प्राप्त डीनोइज्ड ईसीजी सिग्नल का गैर-रेखीय गतिशील प्रणाली विश्लेषण प्रस्तुत

किया गया है। प्रस्तावित चरण अंतरिक्ष विश्लेषण आधारित तकनीक गंभीर रूप से बीमार रोगियों में हृदय अतालता का पता लगाने में प्रभावी साबित हुई है और इसलिए गहन देखभाल इकाइयों में हृदय रोग के निदान में सहायता कर सकती है।

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List of Notations and Abbreviations

$\exists$	there exists
AR	Autoregressive
ARMA	Autoregressive Moving Average
ASMFB	Analytic Signal Matched Filter Bank
CWT	Continuous Wavelet Transform
DFT	Discrete Fourier Transform
DSP	Digital Signal Processing
DWT	Discrete Wavelet Transform
EMD	Empirical Mode Decomposition
EWT	Empirical Wavelet Transform
FB	Filter Bank
FDM	Fourier Decomposition Method
FR	Frequency Representation
FT	Fourier Transform
FIR	Finite Impulse Response
IDFT	Inverse Discrete Fourier Transform
IIR	Infinite Impulse Response
LHS	Left Hand Side

LPTV	Linear Periodically Time Varying
LS	Least Square
LTI	Linear Time Invariant
MMSE	Minimum Mean Square Error
NUFB	Non-Uniform Filter Bank
PCA	Principal Component Analysis
PRFB	Perfect Reconstruction Filter Bank
PSD	Power Spectral Density
RD	Rihaczek Distribution
RHS	Right Hand Side
SMAFB	Signal Matched Analysis Filter Bank
SMSFB	Signal Matched Synthesis Filter Bank
SMFB	Signal Matched Filter Bank
SNR	Signal to Noise Ratio
STFT	Short-Time Fourier Transform
TR	Time Representation
TFA	Time Frequency Analysis
TFD	Time Frequency Distribution
TFR	Time Frequency Representation
UFB	Uniform Filter Bank
VMD	Variable Mode Decomposition
WSCS	Wide Sense Cyclo-Stationary
WSS	Wide Sense Stationary

WVD Wigner-Ville Distribution