

Speech Enhancement with Score-Based Generative Models in the Complex STFT Domain

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Abstract

Score-based generative models (SGMs) have recently shown impressive results for difficult generative tasks such as the unconditional and conditional generation of natural images and audio signals. In this work, we extend these models to the complex short-time Fourier transform (STFT) domain, proposing a novel training task for speech enhancement using a complex-valued deep neural network. We derive this training task within the formalism of stochastic differential equations (SDEs), thereby enabling the use of predictor-corrector samplers. We provide alternative formulations inspired by previous publications on using generative diffusion models for speech enhancement, avoiding the need for any prior assumptions on

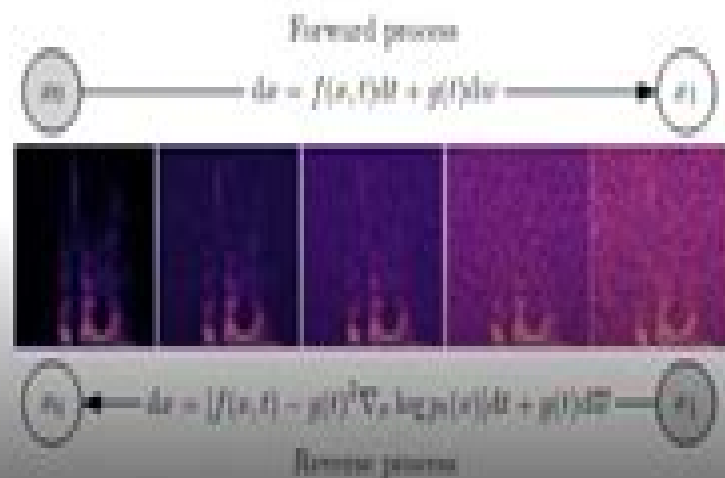


Figure 1: The forward and reverse process on a spectrogram as a solution to an SDE. The reverse process gradually converts the corrupted signal x_1 into a clean speech spectrogram x_0 .

Speech Enhancement In The Stft Domain

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Mahdi Parchami



Speech Enhancement In The Stft Domain Speech Enhancement In The Stft Domain:

Speech Enhancement in the STFT Domain Jacob Benesty, Jingdong Chen, Emanuel A.P. Habets, 2011-09-18 This work addresses this problem in the short time Fourier transform STFT domain We divide the general problem into five basic categories depending on the number of microphones being used and whether the interframe or interband correlation is considered The first category deals with the single channel problem where STFT coefficients at different frames and frequency bands are assumed to be independent In this case the noise reduction filter in each frequency band is basically a real gain Since a gain does not improve the signal to noise ratio SNR for any given subband and frame the noise reduction is basically achieved by lifting the subbands and frames that are less noisy while weighing down on those that are more noisy The second category also concerns the single channel problem The difference is that now the interframe correlation is taken into account and a filter is applied in each subband instead of just a gain The advantage of using the interframe correlation is that we can improve not only the long time fullband SNR but the frame wise subband SNR as well The third and fourth classes discuss the problem of multichannel noise reduction in the STFT domain with and without interframe correlation respectively In the last category we consider the interband correlation in the design of the noise reduction filters We illustrate the basic principle for the single channel case as an example while this concept can be generalized to other scenarios In all categories we propose different optimization cost functions from which we derive the optimal filters and we also define the performance measures that help analyzing them

New Approaches for Speech Enhancement in the Short-Time Fourier Transform Domain Mahdi Parchami, 2016 Speech enhancement aims at the improvement of speech quality by using various algorithms A speech enhancement technique can be implemented as either a time domain or a transform domain method In the transform domain speech enhancement the spectrum of clean speech signal is estimated through the modification of noisy speech spectrum and then it is used to obtain the enhanced speech signal in the time domain Among the existing transform domain methods in the literature the short time Fourier transform STFT processing has particularly served as the basis to implement most of the frequency domain methods In general speech enhancement methods in the STFT domain can be categorized into the estimators of complex discrete Fourier transform DFT coefficients and the estimators of real valued short time spectral amplitude STSA Due to the computational efficiency of the STSA estimation method and also its superior performance in most cases as compared to the estimators of complex DFT coefficients we focus mostly on the estimation of speech STSA throughout this work and aim at developing algorithms for noise reduction and reverberation suppression First we tackle the problem of additive noise reduction using the single channel Bayesian STSA estimation method In this respect we present new schemes for the selection of Bayesian cost function parameters for a parametric STSA estimator namely the W SA estimator based on an initial estimate of the speech and also the properties of human auditory system We further use the latter information to design an efficient flooring scheme for the

gain function of the STSA estimator Next we apply the generalized Gaussian distribution GGD to the WSA estimator as the speech STSA prior and propose to choose its parameters according to noise spectral variance and a priori signal to noise ratio SNR The suggested STSA estimation schemes are able to provide further noise reduction as well as less speech distortion as compared to the previous methods Quality and noise reduction performance evaluations indicated the superiority of the proposed speech STSA estimation with respect to the previous estimators Regarding the multi channel counterpart of the STSA estimation method first we generalize the proposed single channel WSA estimator to the multi channel case for spatially uncorrelated noise It is shown that under the Bayesian framework a straightforward extension from the single channel to the multi channel case can be performed by generalizing the STSA estimator parameters i.e. and Next we develop Bayesian STSA estimators by taking advantage of speech spectral phase rather than only relying on the spectral amplitude of observations in contrast to conventional methods This contribution is presented for the multi channel scenario with single channel as a special case Next we aim at developing multi channel STSA estimation under spatially correlated noise and derive a generic structure for the extension of a single channel estimator to its multi channel counterpart It is shown that the derived multi channel extension requires a proper estimate of the spatial correlation matrix of noise Subsequently we focus on the estimation of noise correlation matrix that is not only important in the multi channel STSA estimation scheme but also highly useful in different beamforming methods Next we aim at speech reverberation suppression in the STFT domain using the weighted prediction error WPE method The original WPE method requires an estimate of the desired speech spectral variance along with reverberation prediction weights leading to a sub optimal strategy that alternatively estimates each of these two quantities Also similar to most other STFT based speech enhancement methods the desired speech coefficients are assumed to be temporally independent while this assumption is inaccurate Taking these into account first we employ a suitable estimator for the speech spectral variance and integrate it into the estimation of the reverberation prediction weights In addition to the performance advantage with respect to the previous versions of the WPE method the presented approach provides a good reduction in implementation complexity Next we take into account the temporal correlation present in the STFT of the desired speech namely the inter frame correlation IFC and consider an approximate model where only the frames within each segment of speech are considered as correlated Furthermore an efficient method for the estimation of the underlying IFC matrix is developed based on the extension of the speech variance estimator proposed previously The performance results reveal lower residual reverberation and higher overall quality provided by the proposed method Finally we focus on the problem of late reverberation suppression using the classic speech spectral enhancement method originally developed for additive noise reduction As our main contribution we propose a novel late reverberant spectral variance LRSV estimator which replaces the noise spectral variance in order to modify the gain function for reverberation suppression The suggested approach employs a modified version of the WPE method in a model

based smoothing scheme used for the estimation of the LRSV According to the experiments the proposed LRSV estimator outperforms the previous major methods considerably and scores the closest results to the theoretically true LRSV estimator Particularly in case of changing room impulse responses RIRs where other methods cannot follow the true LRSV estimator accurately the suggested estimator is able to track true LRSV values and results in a smaller tracking error We also target a few other aspects of the spectral enhancement method for reverberation suppression which were explored before only for the purpose of noise reduction These contributions include the estimation of signal to reverberant ratio SRR and the development of new schemes for the speech presence probability SPP and spectral gain flooring in the context of late reverberation suppression

Canonical Correlation Analysis in Speech Enhancement Jacob Benesty, Israel

Cohen, 2017-08-31 This book focuses on the application of canonical correlation analysis CCA to speech enhancement using the filtering approach The authors explain how to derive different classes of time domain and time frequency domain noise reduction filters which are optimal from the CCA perspective for both single channel and multichannel speech enhancement Enhancement of noisy speech has been a challenging problem for many researchers over the past few decades and remains an active research area Typically speech enhancement algorithms operate in the short time Fourier transform STFT domain where the clean speech spectral coefficients are estimated using a multiplicative gain function A filtering approach which can be performed in the time domain or in the subband domain obtains an estimate of the clean speech sample at every time instant or time frequency bin by applying a filtering vector to the noisy speech vector Compared to the multiplicative gain approach the filtering approach more naturally takes into account the correlation of the speech signal in adjacent time frames In this study the authors pursue the filtering approach and show how to apply CCA to the speech enhancement problem They also address the problem of adaptive beamforming from the CCA perspective and show that the well known Wiener and minimum variance distortionless response MVDR beamformers are particular cases of a general class of CCA based adaptive beamformers

Speech Enhancement Shoji Makino, Jingdong Chen, 2005

We live in a noisy world In all applications telecommunications hands free communications recording human machine interfaces etc that require at least one microphone the signal of interest is usually contaminated by noise and reverberation As a result the microphone signal has to be cleaned with digital signal processing tools before it is played out transmitted or stored This book is about speech enhancement Different well known and state of the art methods for noise reduction with one or multiple microphones are discussed By speech enhancement we mean not only noise reduction but also dereverberation and separation of independent signals These topics are also covered in this book However the general emphasis is on noise reduction because of the large number of applications that can benefit from this technology The goal of this book is to provide a strong reference for researchers engineers and graduate students who are interested in the problem of signal and speech enhancement To do so we invited well known experts to contribute chapters covering the state of the art in this focused field

TOC Introduction

Study of the Wiener Filter for Noise Reduction Statistical Methods for the Enhancement of Noisy Speech Single und Multi Microphone Spectral Amplitude Estimation Using a Super Gaussian Speech Model From Volatility Modeling of Financial Time Series to Stochastic Modeling and Enhancement of Speech Signals Single Microphone Noise Suppression for 3G Handsets Based on Weighted Noise Estimation Signal Subspace Techniques for Speech Enhancement Speech Enhancement Application of the Kalman Filter in the Estimate Maximize EM Framework Speech Distortion Weighted Multichannel Wiener Filtering Techniques for Noise Reduction Adaptive Microphone Arrays Employing Spatial Quadratic Soft Constraints and Spectral Shaping Single Microphone Blind Dereverberation Separation and Dereverberation of Speech Signals with Multiple Microphones Frequency Domain Blind Source Separation Subband Based Blind Source Separation Real Time Blind Source Separation for Moving Speech Signals Separation of Speech by Computational Auditory Scene Analysis *Robust Speech Recognition of Uncertain or Missing Data* Dorothea Kolossa, Reinhold Haeb-Umbach, 2011-07-14 Automatic speech recognition suffers from a lack of robustness with respect to noise reverberation and interfering speech The growing field of speech recognition in the presence of missing or uncertain input data seeks to ameliorate those problems by using not only a preprocessed speech signal but also an estimate of its reliability to selectively focus on those segments and features that are most reliable for recognition This book presents the state of the art in recognition in the presence of uncertainty offering examples that utilize uncertainty information for noise robustness reverberation robustness simultaneous recognition of multiple speech signals and audiovisual speech recognition The book is appropriate for scientists and researchers in the field of speech recognition who will find an overview of the state of the art in robust speech recognition professionals working in speech recognition who will find strategies for improving recognition results in various conditions of mismatch and lecturers of advanced courses on speech processing or speech recognition who will find a reference and a comprehensive introduction to the field The book assumes an understanding of the fundamentals of speech recognition using Hidden Markov Models

A Perspective on Single-channel Frequency-domain Speech Enhancement Jacob Benesty, Yiteng Huang, 2011 This book focuses on a class of single channel noise reduction methods that are performed in the frequency domain via the short time Fourier transform STFT The simplicity and relative effectiveness of this class of approaches make them the dominant choice in practical systems Even though many popular algorithms have been proposed through more than four decades of continuous research there are a number of critical areas where our understanding and capabilities still remain quite rudimentary especially with respect to the relationship between noise reduction and speech distortion All existing frequency domain algorithms no matter how they are developed have one feature in common the solution is eventually expressed as a gain function applied to the STFT of the noisy signal only in the current frame As a result the narrowband signal to noise ratio SNR cannot be improved and any gains achieved in noise reduction on the fullband basis come with a price to pay which is speech distortion In this book we present a new perspective on the problem by exploiting the difference between

speech and typical noise in circularity and interframe self correlation which were ignored in the past By gathering the STFT of the microphone signal of the current frame its complex conjugate and the STFTs in the previous frames we construct several new multiple observation signal models similar to a microphone array system there are multiple noisy speech observations and their speech components are correlated but not completely coherent while their noise components are presumably uncorrelated Therefore the multichannel Wiener filter and the minimum variance distortionless response MVDR filter that were usually associated with microphone arrays will be developed for single channel noise reduction in this book This might instigate a paradigm shift geared toward speech distortionless noise reduction techniques A Conceptual Framework for Noise Reduction Jacob Benesty,Jingdong Chen,2015-03-31 Though noise reduction and speech enhancement problems have been studied for at least five decades advances in our understanding and the development of reliable algorithms are more important than ever as they support the design of tailored solutions for clearly defined applications In this work the authors propose a conceptual framework that can be applied to the many different aspects of noise reduction offering a uniform approach to monaural and binaural noise reduction problems in the time domain and in the frequency domain and involving a single or multiple microphones Moreover the derivation of optimal filters is simplified as are the performance measures used for their evaluation Speech Enhancement Jacob Benesty,Shoji Makino,Jingdong Chen,2006-03-30 We live in a noisy world In all applications telecommunications hands free communications recording human machine interfaces etc that require at least one microphone the signal of interest is usually contaminated by noise and reverberation As a result the microphone signal has to be cleaned with digital signal processing tools before it is played out transmitted or stored This book is about speech enhancement Different well known and state of the art methods for noise reduction with one or multiple microphones are discussed By speech enhancement we mean not only noise reduction but also dereverberation and separation of independent signals These topics are also covered in this book However the general emphasis is on noise reduction because of the large number of applications that can benefit from this technology The goal of this book is to provide a strong reference for researchers engineers and graduate students who are interested in the problem of signal and speech enhancement To do so we invited well known experts to contribute chapters covering the state of the art in this focused field *Audio Source Separation and Speech Enhancement* Emmanuel Vincent,Tuomas Virtanen,Sharon Gannot,2018-10-22 Learn the technology behind hearing aids Siri and Echo Audio source separation and speech enhancement aim to extract one or more source signals of interest from an audio recording involving several sound sources These technologies are among the most studied in audio signal processing today and bear a critical role in the success of hearing aids hands free phones voice command and other noise robust audio analysis systems and music post production software Research on this topic has followed three convergent paths starting with sensor array processing computational auditory scene analysis and machine learning based approaches such as independent component analysis respectively This

book is the first one to provide a comprehensive overview by presenting the common foundations and the differences between these techniques in a unified setting

Key features

- Consolidated perspective on audio source separation and speech enhancement
- Both historical perspective and latest advances in the field e g deep neural networks
- Diverse disciplines array processing machine learning and statistical signal processing
- Covers the most important techniques for both single channel and multichannel processing

This book provides both introductory and advanced material suitable for people with basic knowledge of signal processing and machine learning

Thanks to its comprehensiveness it will help students select a promising research track

researchers leverage the acquired cross domain knowledge to design improved techniques and engineers and developers choose the right technology for their target application scenario

It will also be useful for practitioners from other fields e g acoustics multimedia phonetics and musicology willing to exploit audio source separation or speech enhancement as pre processing tools for their own needs

Fractional Fourier Transform Techniques for Speech Enhancement

Prajna Kunche, N. Manikanthababu, 2020-04-16

This book explains speech enhancement in the Fractional Fourier Transform FRFT domain and investigates the use of different FRFT algorithms in both single channel and multi channel enhancement systems which has proven to be an ideal time frequency analysis tool in many speech signal processing applications

The authors discuss the complexities involved in the highly non stationary signal processing and the concepts of FRFT for speech enhancement applications

The book explains the fundamentals of FRFT as well as its implementation in speech enhancement

Theories of different FRFT methods are also discussed

The book lets readers understand the new fractional domains to prepare them to develop new algorithms

A comprehensive literature survey regarding the topic is also made available to the reader

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Speech Enhancement In The Stft Domain Speech Enhancement In The Stft Domain Introduction

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