A Low Latency Digital Filter using Recurrent Neural Network

Dissertation-I (MCS-392)

Submitted in partial fulfillment of the requirements for the degree of Master of Technology

College of Computing Sciences and Information Technology
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Session: 2023-24

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M.Tech (CSE)
III Sem

Certificate

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The work presented in dissertation entitled "A Low Latency Digital Filter using Recurrent Neural Network" submitted to the Department of College of Computing Sciences and Information Technology(CCSIT), Teerthanker Mahaveer University, Moradabad, for the award of the degree of Master of Technology in Computer Science and Engineering, during the session 2023-24, is my original work. I have neither plagiarized nor submitted the same work for the award of any degree.

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Acknowledgement

I would like to express my sincere gratitude to my supervisors Ms. Sukrati Jain & Mr. Vikas Deswal for providing me the guidance, valuable advice and constant encouragement that they provided during this research work. I am also greatly thankful to them as they have given me an opportunity to work on this interesting topic.

I am very grateful to Dr. RK Dwivedi the Director of the College of Computing Sciences & Information Technology for providing me the opportunity to do this research as part of my academic program. This research has not only been a valuable learning experience but has also contributed to the knowledge base of the field.

I would also like to thank my seniors, colleagues and friends who provided me with valuable feedback and suggestions. Their input has significantly improved the quality of this research.

Furthermore, I would like to express my gratitude to Teerthanker Mahaveer University for providing me the necessary resources and infrastructure. The library staff and resources have all played an integral role in the successful completion of the study.

I am grateful to have had the opportunity to study at such an esteemed institution and to have been surrounded by individuals who have pushed me to achieve my best. Thank you, Teerthanker Mahaveer University, for contributing to my academic and personal growth.

Finally, I would like to thank my family for their unwavering support and encouragement throughout the research. Their love and understanding have been a source of strength and inspiration to me.

Once again, thank you to everyone who has contributed to this research.

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1 Introduction

In the realm of digital signal processing, the pursuit of low-latency solutions remains paramount. This research introduces a pioneering approach — the "Low Latency Digital Filter using Recurrent Neural Network." Leveraging the power of Recurrent Neural Networks (RNNs), this innovative filter seeks to overcome the limitations of traditional designs by providing swift adaptability to dynamic input signals. This brief overview highlights the motivation, design principles, and potential applications of this novel digital filter, aiming to contribute to the evolution of efficient real-time signal processing systems.

Digital Filters are the heart of DSP. From medical sector to entertainment industry, all the signal processing in the present digital world requires to deal with the discrete-time signals. Most of the time these signals requires filtering which is done by using a digital system known as the digital filter. On the other hand, RNNs in the field of Deep Learing are doing a great job. These type of neural networks are capable of predicting sequential data. This study is about presenting a new approach of designing a digital filter using RNN due to which one can achive a high quality output less latency.

Traditional filters, while effective, often face limitations in adapting swiftly to dynamic and rapidly changing input signals. The introduction of Recurrent Neural Networks, known for their ability to model temporal dependencies and handle sequential data, presents an intriguing avenue for advancing the field of digital filtering. This synopsis aims to present a comprehensive overview of the proposed "Low Latency Digital Filter using Recurrent Neural Network," shedding light on its design principles, potential applications, and the anticipated advantages it offers in terms of reduced latency and improved adaptability.

2 Problem Statement

Traditional digital filter design lacks adaptability to dynamic signals which will introduce the latency problem. The potential benefits and limitations of integrating Recurrent Neural Networks (RNNs) into digital filters remain unclear, creating a research gap that needs exploration.

2.1 Literature Survey

Some various methods for designing digital Finite Impulse Response (FIR) filters include frequency sampling methods, windowing-based methods, optimization based methods, and evolutionary optimization methods. Some of the reviewed literature about that are as follows:

Ref. No.	Paper Title	Findings	Year
[1]	A Review of Digital FIR Filter Design in Communication Systems	Various optimization techniques to design digital FIR filters.	2021
[2]	Comparative Analysis of RNN Versus IIR Digital Filtering to Optimize Resilience in pH Sensing	RNN-based digital filters have been shown to effectively suppress random pH perturbations.	2023
[3]	Comparison of Different Types of IIR Filters	The paper discusses the advantages of IIR filters over FIR filters.	2016
[4]	Comparison of the design of FIR and IIR filters for a given specification and removal of phase distortion from IIR filters	This paper takes a given specification to design both FIR and IIR filter. An equalizer was also designed to remove the phase distortion of the IIR filter.	2017
[5]	Introduction to Sequence Learning Models: RNN, LSTM, GRU	Limitations of basic RNN and introduces LSTM, GRU & BRNN.	2021

Ref. No.	Paper Title	Findings	Year
[6]	Application of Deep Learning Gated Recurrent Unit in Hybrid Shunt Active Power Filter for Power Quality Enhancement	Unified filtering capability for power quality improvement in a three-phase, four-wire system.	2022
[7]	Fundamentals of recurrent neural network (RNN) and long short-term memory (LSTM) network	RNN framework of approximating an IIR system by an FIR model using LSTM.	2020
[8]	A Hybrid CNN and RNN Variant Model for Music Classification	Music classification task by CNN and variants of RNN.	2023
[9]	A Dynamic Filtering DF-RNN Deep-Learning-Based Approach for EEG-Based Neurological Disorders Diagnosis	EEG-based diagnosis system well suited for two neurological disorders using GRU.	2020
[10]	HMFP-DBRNN: Real-Time Hand Motion Filtering and Prediction via Deep Bidirectional RNN	Parkinson's disease detection using DBRNN.	2019

Ref. No.	Paper Title	Findings	Year
[11]	Time Domain Recursive Digital Filter Modeling Based on Recurrent Neural Network Training	Modelling of time domain recursive digital filter using RNN.	2004
[12]	A comparison between recurrent neural network architectures for digital equalization	This paper shows a comparison between three different first-order RNN architectures.	1997

Some textbooks and online resources which provides the concept of Digital Signal Processing(DSP) and also discussed about the fundamentals of Analog and Digital filter design process. One of them provides the detailed concepts about Deep Learning, their applications, some standard deep learning models and the intuition behind them [13] [14] [15].

2.2 Hypothesis Formulation

Better performance of a digital filter can be achived by designing a constant phase response digital filter using RNN with filter coefficients. Incorporating RNNs into digital filter design will enhance adaptability and performance, particularly in handling non-stationary signals and complex patterns.

3 Research Gap

Digital filters have become increasingly popular in various applications due to their numerous advantages. However, they also have some issues that should be considered as follows:

- **Sampling rate:** Digital filters require a high sampling rate to achieve a high level of accuracy, which can be challenging in some applications.

- **Complexity:** Digital filters can be more complex to design and implement than analog filters, requiring specialized knowledge and software tools.
- **Latency:** Digital filters can introduce a delay, or latency, in signal processing due to the computation time required.
- **Nonlinear distortion:** Digital filters can introduce nonlinear distortion, resulting in signal distortion and degradation.
- **Quantization noise:** Digital filters are subject to quantization noise, which can reduce the quality of the processed signal.

4 Objective

The objective of this research is to explore the integration of Recurrent Neural Networks (RNNs) in digital filter design for signal processing applications. The focus is on enhancing the adaptability and performance of digital filters in various scenarios, such as speech signal processing, image processing, and adaptive filtering in non-stationary environments.

5 Research Methodology

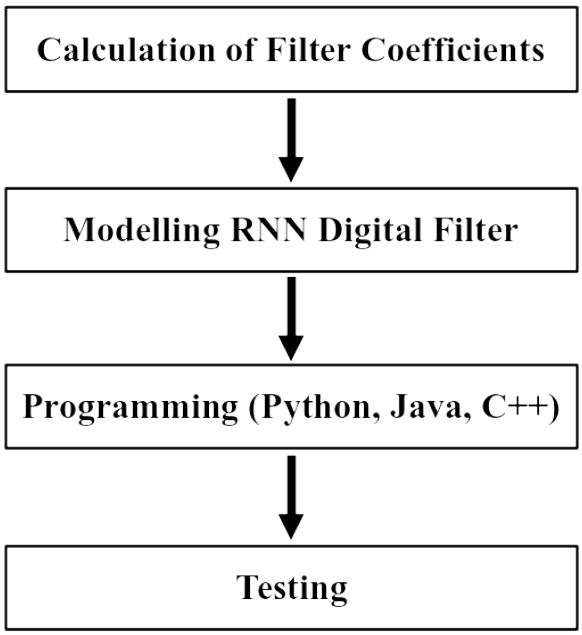

Figure 1: Steps Followed in Implementation

1. **Calculation of Filter Coefficients:**
    - Define specifications and select a design method.
    - Formulate math expressions, compute coefficients, and verify accuracy.
    - Document coefficients and adjustments.

2. **Modelling of RNN Digital Filter:**
    - Choose RNN architecture (e.g., LSTM).
    - Define input/output layers and integrate filter coefficients.
    - Prepare training data for RNN.

3. **Programming (Python, Java, C++):**
    - Choose a language (e.g., Python with TensorFlow).
    - Implement filter coefficients and RNN model.

4. **Testing:**
    - Generate diverse test datasets.
    - Evaluate RNN filter performance using metrics.
    - Refine model iteratively if needed.
    - Document test results for future reference.

6 Proposed Work

The proposed work can be divided into several key tasks:

1. **Investigate RNN-Based Filters:**
    - Review relevant literature on RNNs in filter design.
    - Assess suitability of RNN types for digital filters.

2. **Framework Development:**
   - Investigate methods for calculating filter coefficients with RNNs.
   - Develop a framework for seamless integration.
3. **Python Implementation:**
   - Choose Python with TensorFlow or PyTorch.
   - Implement RNN-based digital filter with calculated coefficients.
4. **Performance Evaluation:**
   - Generate diverse datasets for testing.
   - Evaluate performance using key metrics (e.g., SNR, MSE).
5. **Documentation and Analysis:**
   - Document design, implementation, and testing.
   - Conduct analysis of advantages and limitations.

7 Conclusion & Future Scope

The integration of RNNs into digital filter design represents a promising avenue for addressing challenges in adaptive signal processing. Current research indicates the potential of RNN-based filters in various applications, with ongoing efforts aimed at improving training efficiency, generalization capabilities, and interpretability. As the field continues to evolve, the combination of advanced neural network architectures and signal processing expertise holds the key to unlocking the full potential of digital filters using RNNs.

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Appendix

Activity Chart

S. No		Activity			Work Process Month Wise (Aug 2023 to Dec 2023)	
		Aug	Sep	Oct	Nov	Dec
1	Topic Finalization	✓				
2	Data collection of Literature Review		✓			
3	Problem formulation & Research Proposal			✓		
4	Literature Review & Proposed Study			✓		
5	Validation of Study & feedback from Supervisor				✓	
6	Summary Conclusion				✓	
7	Final write up and Dissertation-I submission					✓