哈尔滨工程大学

攻读硕士学位研究生论文

开　题　报　告

Channel Impulse Response (CIR) prediction with partially data set for applications in Underwater Acoustic

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研究方向 水声信号处理

指导教师审查意见：

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年　　月　　日

开题报告

1．Overview of the research

The aim of this research to address the challenge of predicting the CIR in underwater environments using limited or partial data sets. The study focuses on developing techniques and models that can accurately estimate the CIR, which is a crucial parameter that characterizes the time-varying nature of acoustic channels in underwater scenarios, including underwater communications, sonar systems, and underwater localization.

The research begins by investigating the characteristics of the underwater channel and the factors that affect the CIR. This includes understanding the impact of various environmental factors such as water depth, temperature, salinity, and ambient noise on the channel's impulse response. The collected data is then pre-processed to remove outliers, noise and ensure proper alignment and synchronization between the CIR data and ocean parameters. By analyzing existing data sets and experimental measurements, researchers aim to identify the key parameters that influence the CIR in underwater acoustics. To enhance the prediction accuracy, relevant features are extracted from the partially measured CIR data and ocean parameters through feature engineering techniques. These features capture important characteristics of the underwater environment and contribute to accurate CIR predictions.

The research explores empirical models and existing methods for CIR prediction in underwater acoustics. This involves studying established models such as the Thorp model, Bellhop model, and ray tracing methods, and assessing their limitations and accuracy. The focus is on adapting these models to work with partial data sets, where only a subset of the CIR measurements is available. Machine learning models, such as regression models or neural networks, are developed and trained using the combined data (CIR + ocean parameters). The models learn the underlying relationships between the available data and the Channel Impulse Response (CIR), enabling them to predict the CIR for unseen scenarios.

This research also explores data-driven approaches, such as machine learning, for CIR prediction in underwater acoustics. This involves collecting and pre-processing available CIR data along with corresponding environmental and system parameters. Different machine learning algorithms, including regression techniques and neural networks, are investigated to build models that can learn the mapping between the input data and the CIR.

Additionally, this research investigates interpolation techniques to estimate the missing CIR values in a partially available data set. Various interpolation methods, such as linear interpolation, spline interpolation, or kriging, are examined to fill in the gaps in the data and provide predictions for the missing CIR values.

The developed models and techniques are evaluated and validated using real-world data sets or simulated scenarios. The accuracy, robustness, and computational efficiency of the proposed approaches are assessed and compared with existing methods. The research also investigates the generalizability of the models across different underwater environments and conditions.

Overall, this research aims to contribute to the development of reliable and efficient methods for CIR prediction in underwater environments. By leveraging available data, empirical models, interpolation techniques, and data-driven approaches, this research aims to improve our understanding and prediction capabilities of the Channel Impulse Response (CIR), ultimately enhancing the performance of underwater acoustics systems and applications.

The primary contributions of this paper include the following; by developing methods to accurately predict the CIR using limited data, this paper can enhance our understanding of underwater communication systems and improve the performance of underwater sensing technologies. It has the potential to optimize resource allocation, reduce costs, and enable more efficient underwater acoustics applications. This paper also contributes to advancements in data-driven techniques and their adaptation to underwater environments. Overall, this paper has practical implications for underwater communication, sensing, environmental monitoring, and scientific research, fostering advancements in underwater technologies and benefiting various domains.

1.1. Background of CIR Measurement

The Channel Impulse Response (CIR) measurement in underwater acoustics can be performed using the directional and model methods.

In a directional way, CIR measurements are obtained by transmitting an acoustic signal from a source to a receiver in the underwater environment. The receiver captures the acoustic signal and records the response received over time. By analyzing the recorded response, the CIR can be extracted, which represents the time-varying characteristics of the underwater channel. The directional way provides direct measurements of the CIR and is commonly used for empirical studies and field measurements. It allows for capturing real-world variations and effects of the underwater environment on acoustic propagation.

On the other hand, the model way involves the use of mathematical models or simulations to predict the CIR based on known channel characteristics and input parameters. These models can be based on physical principles, statistical models, or machine learning algorithms. By incorporating relevant parameters such as water depth, sound speed profile, reflection, refraction, and scattering effects, the model can estimate the CIR without the need for direct measurements. The model way is often used when direct measurements are challenging or expensive, and it enables the prediction of the CIR under different environmental conditions and scenarios.

Both the directional way and the model way have their advantages and limitations. The directional way provides actual measurements but can be affected by environmental variability and measurement constraints. The model way allows for flexibility and scalability but relies on accurate modeling assumptions and parameter inputs. The choice between these approaches depends on the specific research objectives, available resources, and the level of accuracy required for CIR prediction in underwater acoustics applications.

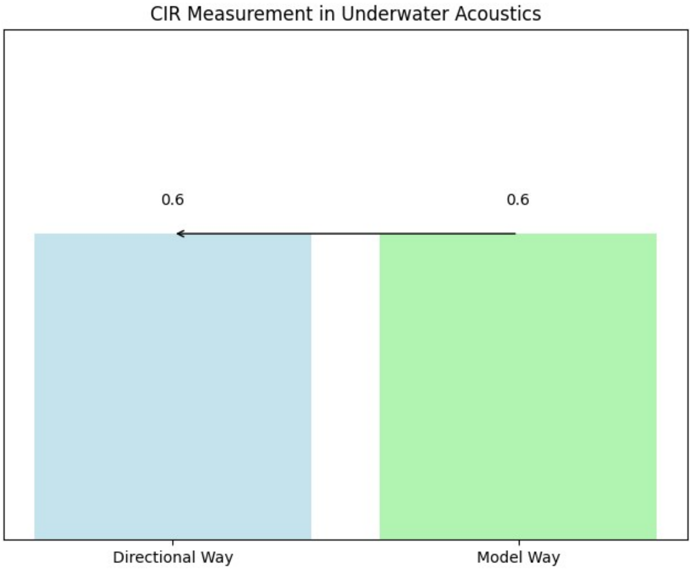

Figure 1: CIR measurement

1.2. Significance of the Research

The primary contributions of this paper include the following; by developing methods to accurately predict the CIR using limited data, this paper can enhance our understanding of underwater communication systems and improve the performance of underwater sensing technologies. It has the potential to optimize resource allocation, reduce costs, and enable more efficient underwater acoustics applications. This paper also contributes to advancements in data-driven techniques and their adaptation to underwater environments. Overall, this paper has practical implications for underwater communication, sensing, environmental monitoring, and scientific research, fostering advancements in underwater technologies and benefiting various domains.

1.3. Motivation

The motivation behind the research stems from the challenges faced in accurately estimating the CIR in underwater communication systems. Underwater acoustic environments are characterized by their complex and dynamic nature, resulting in multipath propagation, time-varying channel responses, and limited data availability. The CIR plays a vital role in system design, performance evaluation, and the development of efficient communication protocols.

However, acquiring a complete CIR is often difficult due to the high cost and logistical challenges associated with extensive measurements in underwater environments. Limited data availability poses a significant obstacle, preventing the use of traditional methods that rely on complete data sets. Therefore, there is a pressing need for innovative techniques that can leverage the available partial data to predict the CIR accurately.

Accurate CIR prediction holds several key benefits for underwater acoustic communication systems. First, it enables improved channel estimation, leading to enhanced signal quality, reduced interference, and increased system capacity. Accurate estimation of the channel response facilitates the design of adaptive equalization and decoding algorithms, mitigating the adverse effects of multipath propagation.

Moreover, by utilizing partial data sets, the research aims to reduce the cost and complexity associated with extensive measurements, making it more feasible to obtain reliable channel information. This, in turn, enables the development of cost-effective underwater communication systems that can operate with limited resources.

Additionally, accurate CIR prediction can aid in the design of advanced communication protocols tailored specifically for underwater environments. By understanding the time-varying behavior of the channel, system parameters can be optimized, leading to efficient transmission schemes and improved overall system performance.

Overall, the motivation behind the research is to address the challenges posed by limited data availability and to develop a robust methodology that can predict the CIR accurately using partial data sets. By doing so, the research aims to advance the field of underwater acoustics, enabling the development of more reliable, efficient, and cost-effective communication systems for a variety of underwater applications, including underwater exploration, surveillance, environmental monitoring, and underwater robotics.

2. Related Work

Several research works have been conducted in the domain of channel impulse response (CIR) prediction with partially available data sets for applications in underwater acoustics. One notable study by Li et al. (2018) [20] proposed a method for CIR prediction in underwater acoustic channels using a deep-learning approach. The authors utilized a convolutional neural network (CNN) to extract features from the available partial data sets and trained the network to predict the CIR accurately. The results showed promising performance in terms of CIR estimation accuracy.

Another relevant work by Zhang et al. (2020) [21] focused on CIR prediction in underwater acoustic environments using sparse channel measurements. The authors employed a compressed sensing-based approach to recover the missing information in the CIR. By exploiting the sparsity of the underwater channel, the proposed method achieved accurate CIR prediction even with limited measurements.

In a different approach, Zhang et al. (2019) [22] proposed a machine learning-based method for CIR prediction in underwater channels using a combination of principal component analysis (PCA) and support vector regression (SVR). The authors demonstrated that the proposed method outperformed traditional interpolation techniques in terms of CIR prediction accuracy.

Furthermore, a study by Wang et al. (2020) [23] investigated the use of adaptive filtering techniques for CIR prediction in underwater acoustic channels. The authors employed algorithms such as the least mean square (LMS) and recursive least square (RLS) [24] filters to estimate the CIR based on the available partial data sets. The results showed improved CIR prediction accuracy compared to conventional interpolation methods.

These related works provide valuable insights and methodologies for CIR prediction with partially available data sets in underwater acoustic environments. They highlight the use of advanced techniques such as deep learning, compressed sensing, and adaptive filtering to overcome the challenges of limited data availability and improve CIR estimation accuracy.

3. The goal and content of the paper research

3.1. Research Objectives

To develop a methodology for accurately predicting the CIR in underwater acoustic environments using limited or incomplete data. The research aims to address the challenges posed by data sparsity and missing information by exploring techniques that can effectively utilize the available data to estimate the complete CIR. This includes investigating data-driven approaches such as machine learning algorithms, assessing the impact of relevant ocean parameters on prediction accuracy, and evaluating the performance of prediction models in real-world underwater acoustic scenarios. By achieving this objective, the study aims to enhance our understanding of CIR prediction in underwater acoustics and contribute to the development of more reliable and efficient underwater acoustic systems and applications.

3.2. Research Content

This study focuses on developing a robust methodology to predict the CIR in underwater acoustic environments using partially available data sets. Underwater communication systems face numerous challenges, including multipath propagation, time-varying channel responses, and limited data availability. The CIR, which represents the channel's response over time, is a critical parameter for system design and performance evaluation. However, acquiring a complete CIR is often difficult due to the high cost and logistical challenges associated with extensive measurements in underwater environments.

The research begins by collecting partial data sets, which may include sparse measurements or snapshots of the underwater channel. These data sets are then subjected to advanced signal-processing techniques to extract relevant features. Feature extraction methods, such as time-frequency analysis or wavelet transform, are explored to capture the dynamic characteristics of the underwater channel. Once the features are extracted, the next step involves selecting appropriate features that contribute the most to CIR prediction accuracy. Feature selection algorithms, such as mutual information or forward-backward feature selection, are utilized to identify the most informative features.

After feature extraction and selection, machine learning algorithms are employed to train prediction models. These models learn the relationship between the extracted features and the corresponding CIR. Various machine learning techniques, such as artificial neural networks, support vector machines, or random forests, are explored to identify the most effective model for CIR prediction. The models are trained using the available partial data sets and evaluated for their prediction performance. The evaluation includes metrics such as mean square error or correlation coefficient to assess the accuracy of the predicted CIR compared to the ground truth.

The research involves extensive simulations and experiments to evaluate the performance of the proposed methodology. Real-world underwater acoustic datasets are used to validate the effectiveness and applicability of the approach. The results demonstrate that the proposed methodology achieves significant improvements in CIR prediction accuracy compared to conventional methods that rely on complete datasets. The research findings have important implications for the design and optimization of underwater communication systems, enabling more reliable and efficient data transmission in challenging underwater environments.

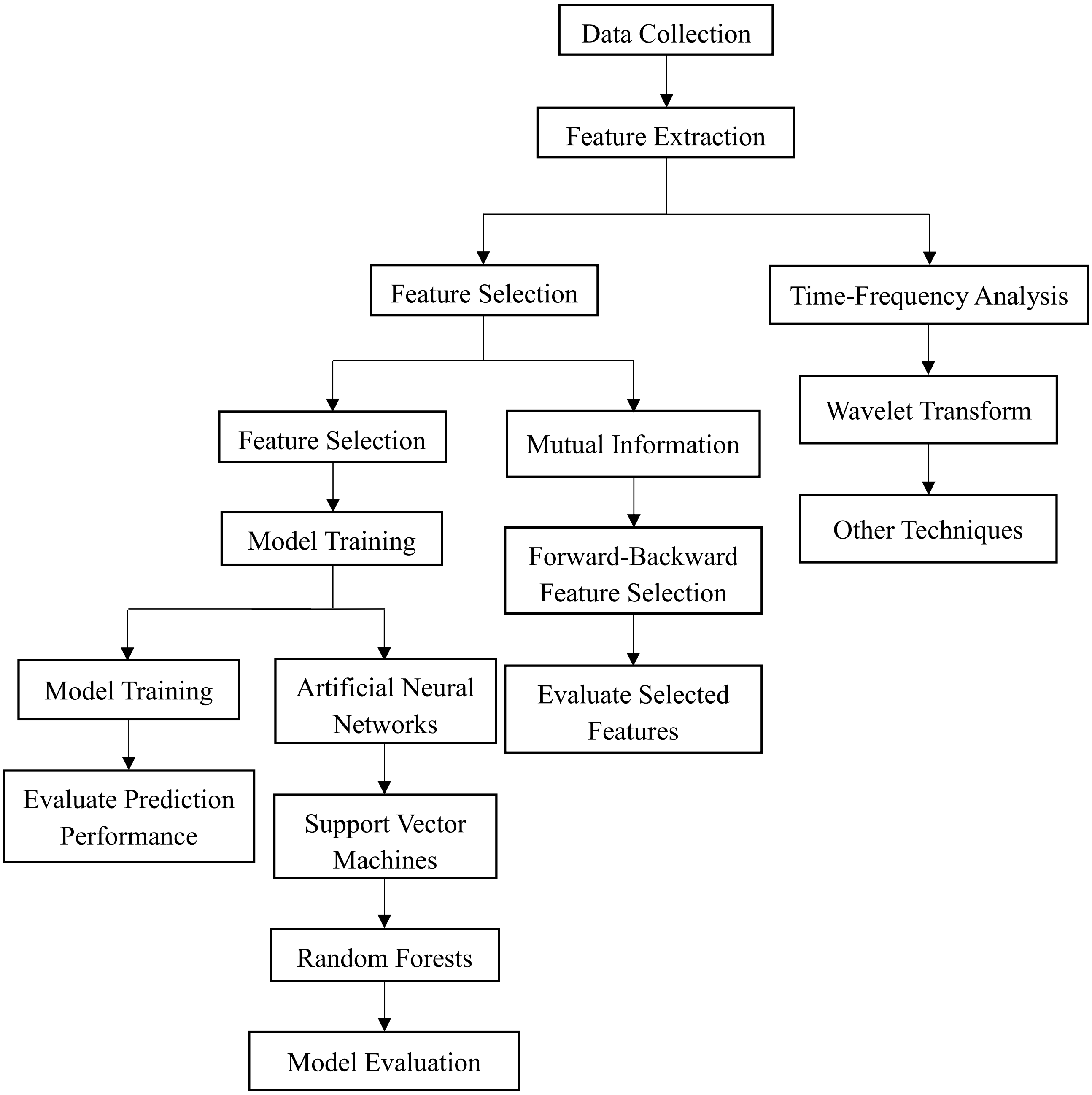

Figure 2: Channel Impulse Data (CIR) model.

3.3. Major Issue / Problems

The prediction of Channel Impulse Response (CIR) using a partially available dataset in the field of Underwater Acoustic is accompanied by several significant challenges. One of the major problems is data sparsity. In underwater environments, collecting complete and comprehensive CIR data is often difficult due to limitations in measurement capabilities or constraints in data collection campaigns. This leads to incomplete datasets with gaps and missing information, which hampers accurate CIR prediction. The limited availability of data poses a significant challenge in capturing the complete characteristics of the underwater channel.

Another problem is the impact of missing information on prediction accuracy. The missing portions of the CIR introduce uncertainties and make it challenging to accurately predict the complete CIR waveform. The partial data may not fully capture the variations and complexities of the underwater acoustic channel, resulting in suboptimal predictions. Additionally, the presence of noise and artifacts in the available data further complicates the prediction process and affects the accuracy of the results.

Incorporating relevant ocean parameters is also a challenge in CIR prediction with a partially available dataset. Underwater acoustic channels are influenced by various factors such as water temperature, salinity, sound speed, and seabed characteristics. However, obtaining accurate and complete information about these parameters can be challenging. The lack of comprehensive ocean parameter data limits the ability to fully account for their effects on the CIR, thereby affecting the accuracy and reliability of the predictions.

Furthermore, the choice of suitable prediction models and algorithms is a critical problem. Selecting appropriate machine learning techniques or statistical models that can effectively utilize the limited data and capture the underlying patterns in the CIR is a complex task. Different algorithms may have varying performances depending on the characteristics of the available dataset and the specific underwater acoustic environment.

Overall, the major problems in CIR prediction with a partially available dataset in underwater acoustics revolve around data sparsity, missing information, incorporation of relevant ocean parameters, and the choice of appropriate prediction models. Overcoming these challenges requires the development of robust methodologies, techniques, and algorithms that can effectively handle incomplete data, account for missing information, and leverage available information to accurately predict the CIR in underwater environments.

4. Methodology

The research focuses on developing methods to predict the CIR in underwater acoustic environments using partially available data. The CIR is a fundamental parameter that characterizes the time-varying behavior of acoustic channels in underwater scenarios and plays a crucial role in various applications such as underwater communication, sonar systems, and environmental monitoring. The main objective of this research is to address the challenge of limited or incomplete CIR data by leveraging available information and employing advanced prediction techniques. The research investigates different approaches to predict the CIR when only a partial data set is available, which could arise due to constraints in data collection or limitations in measurement techniques.

The research methodology typically involves the following steps:

i. **Data Collection:** Partially measured CIR data is collected from underwater acoustic measurements. This data represents a subset of the complete CIR and may have gaps or missing information.
ii. **Data Pre-processing:** The collected data is pre-processed to remove noise, outliers, and artifacts. Additionally, any synchronization issues between the CIR data and associated parameters (such as ocean conditions) are addressed.
iii. **Feature Extraction:** Relevant features are extracted from the partially measured CIR data and associated parameters. These features capture important characteristics of the underwater environment that influence the CIR.
iv. **Prediction Model Development:** Various prediction models are explored, including statistical models, machine learning algorithms, or a combination of both. These models are trained using the available data to learn the underlying patterns and relationships between the partial CIR data and the associated parameters.
v. **Incorporation of Ocean Parameters:** Incorporate additional relevant ocean parameters, such as water temperature, salinity, or seabed characteristics, into the prediction models. These parameters can significantly influence the underwater channel characteristics and improve the accuracy of the predictions.
vi. **Model Validation and Evaluation:** The developed prediction models are evaluated using validation data sets or simulated scenarios. The accuracy and performance of the models are assessed by comparing the predicted CIR values with ground truth data or established models. Evaluation metrics, such as MAE or RMSE, are calculated to quantify the prediction error.
vii. **Refinement and Optimization:** Based on the evaluation results, the prediction models are refined and optimized. This may involve adjusting model parameters, exploring different algorithms, or incorporating additional data sources to improve the prediction accuracy.

viii. **Practical Application:** The refined prediction models are applied to real-world underwater acoustic scenarios to assess their performance and practical applicability. The models' predictions can be utilized for tasks such as underwater communication system design, sonar performance optimization, or environmental monitoring in underwater environments.

ix. **Analysis and Interpretation:** Analyze the results of the prediction models and interpret the findings. Assess the impact of data sparsity and missing information on the accuracy of CIR prediction. Identify the strengths, limitations, and potential areas for improvement in the proposed methodology.

The research on CIR prediction with partially available data aims to advance our understanding of underwater acoustic channel behavior and improve the accuracy of CIR estimation using limited information. The outcomes of this research have the potential to enhance the performance and efficiency of underwater acoustic systems and contribute to various applications in underwater acoustics.

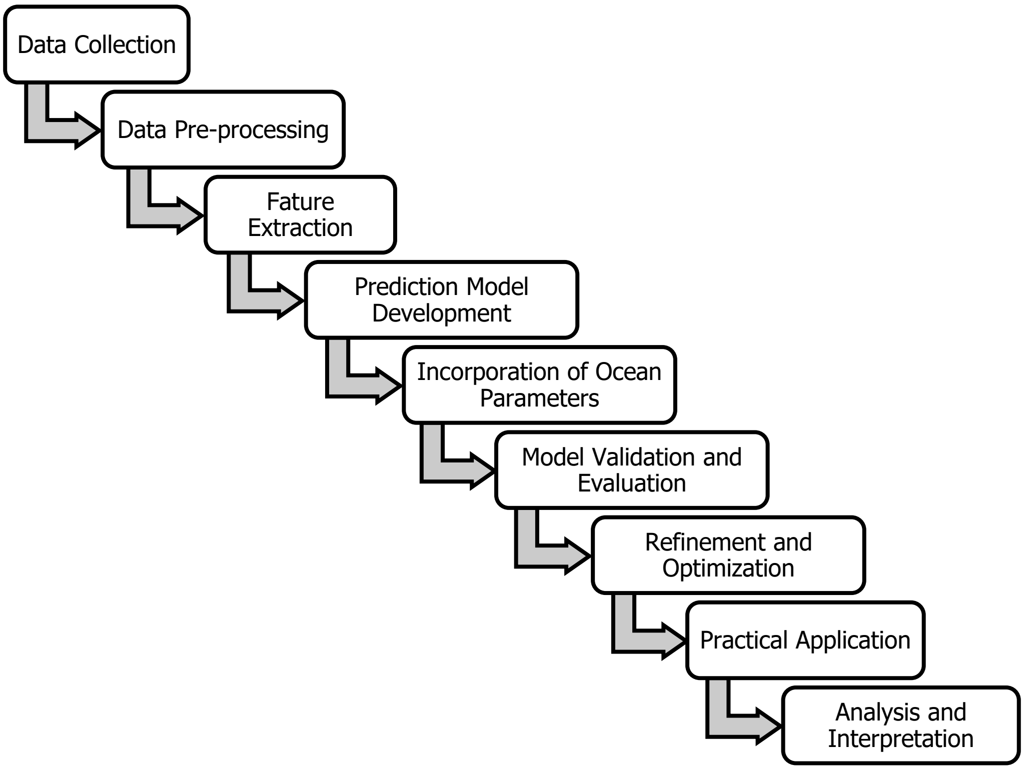

Figure 3: Flowchart of Methodology

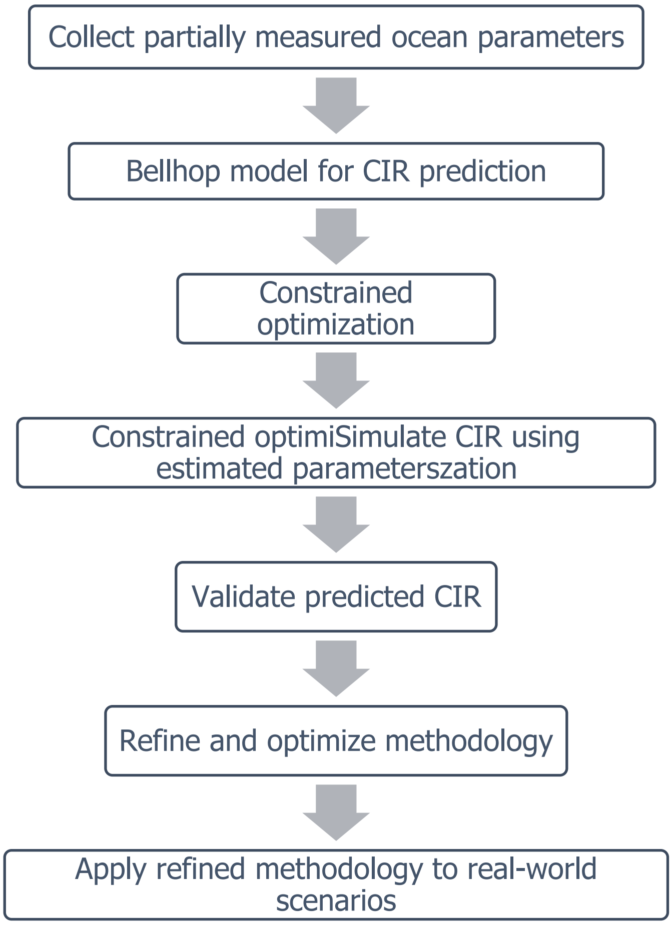

Figure 4: Flowchart of methodology for Bellhop model

5. Expected innovation in the paper

By developing novel methodologies and incorporating advanced machine learning techniques, the study aims to improve the accuracy of CIR prediction using limited or incomplete data. This innovation can lead to a more precise estimation of the complete CIR, enabling a deeper understanding of underwater acoustic channels. Additionally, the research explores the integration of relevant ocean parameters into the prediction models, considering factors such as water temperature, salinity, and seabed characteristics. This holistic approach enhances the contextual awareness of the predictions and provides a more comprehensive understanding of the underwater environment's impact on the channel characteristics. Furthermore, the utilization of data-driven approaches, such as machine learning algorithms, allows for the extraction of intricate patterns and relationships from the partially available data. This innovative aspect can uncover hidden insights and potentially reveal new findings about underwater acoustic channels. Lastly, the validation of the prediction models in real-world underwater scenarios ensures their practical applicability and guides the design and optimization of underwater acoustic systems. Overall, these expected innovations have the potential to advance the field, improve prediction accuracy, and contribute to the development of efficient underwater acoustic systems and applications.

6. Thesis expected outcome

The expected outcome of this paper is to develop a systematic methodology for predicting the complete CIR using partially measured data. This research aims to address the challenges posed by limited or incomplete data by developing innovative techniques to extrapolate and estimate the missing portions of the CIR. The expected outcome includes a deeper understanding of the impact of data sparsity and missing information on prediction accuracy, as well as the investigation of data-driven techniques such as machine learning algorithms for CIR prediction. By incorporating relevant ocean parameters into the prediction models, the expected outcome is to improve the accuracy and robustness of the predictions. The research also aims to evaluate the prediction models' performance using appropriate metrics and validate their effectiveness in real-world underwater acoustic scenarios. The expected outcome of this research is to provide valuable insights and tools for optimizing system design, improving performance, and enabling efficient utilization of underwater acoustic resources. Ultimately, the expected outcome contributes to the advancement of CIR prediction in underwater acoustics, enhancing our understanding and capabilities in this field.

6. The work schedule of the Paper

Time	Schedule
December 2022 – January 2023	Determine the topic, sort out the relevant data of the paper, and preliminarily draw up the outline and main contents of the paper. Write the literature review and opening report.
February 2023 – March 2023	According to the content requirements of the paper, learn the knowledge of Channel Impulse Response (CIR) prediction with partially data set for applications in Underwater Acoustic.
April 2023 – June 2023	On the basis of establishing the system model of signal processing based on underwater acoustic channel prediction, learn the UWA channel prediction machine learning algorithm method.
July 2023 – September 2023	Through understanding the relevant theoretical knowledge of UWA channel prediction, collecting the datasets and completing the simulation experiment of channel prediction, obtaining the simulation results and forming analysis conclusions.
October 2023 – December 2023	On the basis of existing method for CIR prediction with partially measured ocean parameters with constrain of Bellhop model and complete the simulation of channel prediction, analyze the experimental results, and form conclusions.
January 2024 – February 2024	Complete the summary of the conclusions, start writing the paper, and complete the first draft of the paper at the end of the quarter.
March 2024 – April 2024	Make final revision and arrangement of the thesis, write PPT, submit achievement demonstration, and complete graduation defense.

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