Master WAVES
(Waves, Acoustics, Vibrations, Engineering and Sound)

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"Acoustic Frequency Response Modelling of Multi-Bubble Compounds"

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Abstract

Acoustic Frequency Response Modelling of Multi-Bubble Compounds

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Dedication

To mum, and dad, and two lovely cats

Declaration

I declare that no cats have suffered during the experiments

Acknowledgements

I want to thank all the people who didn't disturb me during this master thesis writing process

1 Introduction

The internship was performed as a part of the project within the scope of the hydroacoustic study field of the research instute GEOMAR of the Marine Geology, DeepSeaMonitoring department (DSM) with a collaboration of Technical faculty of the Christian-Albert University in Kiel.

The framework within this internship was in a bubble acoustics, where a simulation work with an experimental measurements in the lab was done.

Initially it started with an available literature review on the current topic. After that the simulation of the acoustic frequency response of the bubble with a SIMO-sonar system was performed using a Thuraisingham model and parameters described in Li et al paper [**li_broadband_2020**]. Different levels of the complexity of the model were done progressively. Starting from the single static bubble modelling, folllowing by adding more bubbles, exploring them in the dynamic state and changing the distribution as well as the location of the bubbles. Simulations of the bubble flares were compared with the emperical data obtained after measurements.

1.1 Literature overview

In the paper of Foldy the mathematical background behind the scattering of the sphere has given a push to the further development of this property in bubbles.

The book of Ainslie has provided fundamentals for the sonar modelling which were essential for understanding while working with a sonar simulation.

(Manasseh et al. 2004 [**manasseh_anisotropy_2004**]) Bubbles produce an acoustic signal owing to compression of the gas in the bubble. The 'spring' of the compressible gas and the mass of liquid around the bubble create a natural oscillator, sending a pressure oscillation through the liquid and interacting with the neighbouring bubbles

(Zhang et al. 2022 [**zhang_efficient_2022**]) This paper provides a volume-scattering strength optimization model. This model allows to estimate the bubble size distribution. It provides a thorough explanation with the help of the case study experiment with a multibeam sonar to identify a bubble leakage in the sea.

It identifies three parameters: two in probability density function of gas leakage bubble sizes and the total number of bubbles inside the sample volume N0. Direct method was used for obtaining parameters.

(Li et al. 2020 [**li_broadband_2020**]) Mentions theory regarding the bubble size distribution and provides the data for the backscattering cross-section of a single bubble. The model of the bubble plume's acoustic backscattering consists of the model of the single bubble, distribution of size of the bubbles and computation of the volume scattering strength.

2 Chapter Two Title

Section 2 is devoted to the theoretical part of this paper. The following assignments were the main interest for exploration in order to progress the current state of the work:

- beamforming
- cross-correlation, matched filtering
- sonar equation
- bubble backscattering, natural frequency, Thuraisingham and Anderson models
- multiple backscattering, other models implementation
- reconstruction of the bubble frequency response from the received signal
- sound propagation concepts
- Wiener filter noise deconstruction

2.1 Beamforming

A beamforming is a way of processing the received or transmitted signal, so that we can direct the directed and amplified signal from teh projector with multiple receivers or transmitters, therefore improving the SNR and eliminating unwanted interfering signals. Also, it can be referred as a spatial filtering.

Withing the scope of the work we have used beamforming in the sonar environment. A conventional beamformer in the form of the delay-and-sum was used.

2.2 Reconstruction of the bubble frequency response from the received signal

It will allow demonstrating the ability to invert the model to find individual bubble contributions from compund analysis. The following equation 1 was the base of the calculations:

$$R = T \times H + N \tag{1}$$

where R is a received signal, T is a transmitted signal by sonar, H is frequency response of the bubble, N is an added background noise.

2.3 Simple version of the multiple scattering

The concept lies in considering each bubble as a source when it scatters an incident wave. Therefore, each bubble will have an influence on another, and also receives a sum of all scatterrings from other bubbles.

Bubbles have to be sufficiently far from each other in order not to be dependent on each others bubble frequency response.

2.4 Different single bubble models

- Anderson

  Anderson model provides a modal solution and allows to model the backscattering cross-section of a single bubble for $ka > 1$ [**anderson_sound_2005**].

- Thuraisingham

  In this paper of Zhang et al. 2022 [**zhang_efficient_2022**] modal solution is used when ka > 1, and Thuraisingham solution is preferred for the ka<1, as the first doesn't consider the bubble damping effect. Such approach can be used for our multiple compund bubble simulation.

- Church, Medwin,

  Andreeva is for fish.

There is a general formula of the gas bubble's rising velocity based on the bubble's volume, which allows us not to consider the bubble shape and its change during the rising process.

2.5 Research on the available mesurement procedures within the literature of the bubble experiments

- Sound signal: narrow band pulse, chirp, noise
- Sonar position: from top, vertical, horizontal
- Bubbles location: in the center of the experimental pool
- Bubble characteristics: emitting a single bubble of the specified radius; a row of bubbles; creating a bubble flare;

Other things which are important for taking into account are:

- Response of the transducer can influence the received signal
- Near field radiation implementation for measurements with a spherical radiation against the plane wave in a far field

Further set of things which are required to perform the experiment are the setup of the equipment required for performing our measurements. Essentially, it will include the sonar, a bubble generator, processing unit as a laptop/computer.

There different papers which have conducted similar experiments on bubble investigation.

The Zhang et al. 2021 [**zhang_experimental_2021**] paper contains description of the experiment for investigation bubble oscillations. In order to produce cavitaion bubbles the setup used a deionised water.

In order to detect the acoustic radiation released by cavitation bubbles a fiber optic hydrophone was employed, which was calibrated and attached to oscilloscope. Among possible things that could affect results were the cleanliness of sensor connector, water quality and wall reflection of the shock wave.

Leblond paper provides a scheme of the vertical and horizontal observation of the acoustic bubble release [**leblond_acoustic_2014**]. Vertical will allow to detect bubbles all along the acoustic beam, while for horizontal we will see only the crossing of the stream.

Some unresolved interesting questions:

- Measurement of the reverberation time of the water tank???

2.6 Wiener filter noise deconstruction

It is one o the signal processing filters which allow us to denoise the signal. Main feature of the Wiener filter is that unlike simpler filters that may only suppress noise or attenuate certain frequency components, the Wiener filter operates on a statistical model of the signal and noise, effectively balancing the trade-off between signal fidelity and noise reduction.

2.7 Sonar equation

The Sonar equation is a fundamental tool in underwater acoustics used to predict the performance of sonar systems. The basic form of the Sonar equation is:

$$SNR = SL - TL + TS - NL \tag{2}$$

Where SNR is the signal-to-noise ratio, SL is the source level, TL is the transmission loss, TS is the target strength, and NL is the noise level.

To implement the Sonar equation, one needs to calculate or estimate each of these parameters. Source level (SL) represents the acoustic power radiated by the sonar system, which can be determined based on the characteristics of the sonar transducer and the electrical input power. Transmission loss (TL) accounts for the attenuation of sound energy as it propagates through the water, considering factors such as spreading loss, absorption, and bottom and surface reflections. Target strength (TS) quantifies the amount of sound energy reflected or scattered by the target, which depends on its size, shape, and composition. Noise level (NL) encompasses all sources of ambient noise in the environment, including thermal noise, wind-generated noise, biological noise, and anthropogenic noise.

3 Chapter Three Title

This section will include the simulation and programming part of the work, experimental part

3.1 Simulation of bubble response

3.2 Experiment of measuring bubbles

Date Performed:	May 17, 2024
Partners:	Viktoriia Boichenko
Instructor:	Christian Kanarski

3.3 Objective

This laboratory project aims to connect theoretical concepts with empirical observations through the use of volume strength backscattering. The primary objective is to illustrate the practical applications of theoretical knowledge acquired during the internship and master's thesis research. By leveraging volume strength backscattering as a key analytical tool, we will examine experimental data, providing insights into how theoretical abstractions translate into concrete experimental methodologies. This integration is designed to promote a comprehensive understanding of the reciprocal relationship between theory and practice, underscoring the significance of a multidimensional approach in scientific inquiry and engineering practice.

Sonars The general principle of the projector SIMO-sonar is in the following way: the signal is emitted with a single transducer and receiving a signal back with several receivers, which in our case were hydrophones. Also, it can be considered with another interpretation. For example, we provide a single output, and obtain multiple input data.

The sonar type is the SIMO-sonar, as we needed to start with a simple model of the current research. The experiments with a MIMO-sonar can be implemented for further research therefore expanding the complexity and variability of usages of the developed model, as [this type provides an improved resolution and enhances the signal-to-noise ratio of the received signal] (http://jset.sas-apublications.com/wp-content/uploads/2017/09/6702529.pdf).

Bubble flare A continuous column of bubbles with the different radii which is emitted with a bubble generator. Minimum bubble size that the machine could produce were

3.4 Experimental model

The experimental setup entails an experiment of bubbles flares detection with a sonar. They were emitted in a water with a bubble generator and observed with the help of the SIMO-sonar with an ultrasound in a laboratory conditions of the water tank.

Preliminary tests of the water tank were performed in order to identify the impulse response of the environment, and verify the correctness of the equipment configuration as well as whether it is in a usable condition.

The primary focus of the observation was the volume strength back scattering (Vs), chosen as the key parameter for assessing the acoustic bubble response with acoustic radiation in the high-frequency range.

3.5 The setup

Our bubble experiment was conducted using a meticulously designed setup aimed at exploring the acoustic frequency response of the bubbles. The experimental arrangement included the following:

- **Bubble generator**: a set of the equipment which included
- **Sonar** it is a projector with 32 hydrophones in an array. The distance between elements is 0.0139 m.
- **Laptop with a processing software KiRAT, contains an inbuilt wave generator**
- **Videocamera**: a mobilephone's camera was used for the experiment recordings

During the experiment different signal types (noise and chirp) and length (2 ms and 10 ms) were used for the analysis of the bubble flares. The emitted central frequency was 50 kHz with a bandwidth of 40 kHz. The sampling frequency was 192 kHz.

- **Noise**: a white noise whose frequency is not dependent on the power spectral density [**ainslie_principles_2010**];
- **Chirp**: a hyperbolic frequency modulation upward signal

3.6 Experimental Data

After the pocessing the date of 23 recorded measurements, a few results as well as comparisons can be presented below.

At the horizontal orientation samples 8 (noise, 10ms) and 11 (chirp, 10ms).

At the vertical orientation sample 19 (noise) and 23 (chirp, 10ms) are seem to be good for comparison.

H_{wall} can be extracted from the initial measurement, calculating an impulse response of the water tank and identifying the location of the walls with the sonar.

3.7 Calculations

- Vs from a single ping
- spectrogram in Audacity for different samples
- bubble localization?
- obtaining H_{bubble}, H_{wall}

3.8 Results and Conclusions

3.9 Discussion of Experimental Uncertainty

4 Chapter Four Title

This section covers the comparison between simulation and experimental results. Their constraints and drawbacks are highlighted.

Results of extracting the bubble response are described.

The simulation of the response from the experiment is trialed.

5 Conclusion