Measurement 60 (2015) 258–266

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Effect of bubble size on underwater noise spectra

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ARTICLE INFO

Article history:
Received 31 January 2014
Received in revised form 30 September 2014
Accepted 16 October 2014
Available online 24 October 2014

Keywords:
Drop size
Rain fall
Natural frequency
Kurtosis

ABSTRACT

This paper describes the interpretations of underwater noise spectra of rainfall on water bodies. It uses a simple methodology of measurement of bubbles of various sizes up to 10 mm in diameter and the comparison of resonating frequencies of the above bubbles with theoretical calculations. The underwater noise of rainfall is a combined effect of drop impacts and bubble bursting. The rain drop size during actual rainfall varies between 0.8 and 5 mm in diameter and the underwater bubble sizes can vary from 0.5 mm to 10 mm in diameter. The detailed description of the experimental results of the underwater spectrum of natural light rain and artificially generated rain are presented. By analyzing the resonating frequencies of underwater bubbles for different type of rainfall, it is plausible to interpret the underwater noise spectrum of rainfall on water bodies and then predict the amount of rainfall.

1. Introduction

Present scenario of rainfall around the world is changing as never before due to many uncontrollable factors such as increased pollution, uncontrolled population expansion, large scale deforestation and global warming. The unpredictable rainfall pattern has brought many new challenges to mankind's survival such as abnormal droughts in some parts and heavy rainfall in other parts of the world. The changes in rainfall pattern on land can be accurately observed from rain gauges, but not so much on water bodies which cover 70.9% of our Earth's surface. Therefore it is necessary to measure the rainfall rate accurately on the oceans to predict the pattern of rainfall. But due to the vastness of the oceans, the task of installation of rain gauges and collection of data in real time is more difficult as compared to that on land. Thus an alternative way to measure the rainfall rate on oceans accurately is critical and analysis of underwater noise spectrum can be such a tool. The research work in the field of underwater noise carried out in the last decades by few scientists is described below.

The underwater noise spectra of rainfall were measured with help of two distinct sources – the raindrop impact and the pulsations of entrained air bubbles. During the heaviest rainfall, the sound–pressure spectrum level is approximately constant at 77 dB [1] (ref: 1 μPa from 1 kHz to 10 kHz). A research was done on spectral characteristics of underwater noise generated by rain falling onto the surface of lake [2]. The study on underwater spectrum of rainfall sound was produced by four acoustically distinctive ranges of drop diameters (D), as 'minuscule drops' ($D \leqslant 0.8$ mm), 'small drops' ($0.8 \leqslant D \leqslant 1.1$ mm), 'mid-size drops' ($1.1 \leqslant D \leqslant 2.2$ mm) and 'large drops' ($D \leqslant 2.2$ mm) [3]. A detailed dynamics associated with bubble bursting was presented [4]. A brief history and explanation on drops impact on liquid surface and the underwater noise of rain were presented with help of experimental observations and numerical simulations [5]. The experimental findings provided evidence for the theory that during the measurement of natural rain, a 14–16 kHz spectral peak is caused

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http://dx.doi.org/10.1016/j.measurement.2014.10.021
0263-2241/

by the ringing of bubbles entrained in the water by the drop impact process [6]. The research on the sound radiated by an oscillating bubble that was released into a water tank was done. Formula for the resonance frequency of a gas bubble in a liquid was also provided [7]. The findings have shown that the initial impact sound produced by a drop was a sharp pulse, while the bubble sound was a decaying sinusoid. It was also found that the sound pressure radiated by the droplet increases with droplets size and impact velocity. The spectra of the impact sound in water shows a broad range of frequencies between 1 kHz and 10 kHz [8]. The first attempts done to describe the underwater noise spectra produced by natural rainfall also found that during the heaviest rainfall, the sound–pressure spectrum level was approximately constant at 77 dB (reference 1 μPa) from below 1 kHz to above 10 kHz [9]. The observation showed that bubble formation by rain is sensitive to size, impact velocity and incidence angle of the rain drops. Further observation was made that bubbles up to 1.8 mm in radius are entrained by large drops, but smaller drops (0.8–1.1 mm in diameter) generate bubbles of only 0.2 mm in radius [10]. Underwater sound produced by rainfall has unique characteristics. The measurement of such a sound signal can be used for the prediction and measurement of rainfall. The simulation results showed that small raindrops which are present in most types of rain are responsible for a unique 15 kHz sound in the spectra. The observation indicate that formation of peaks is comparatively dominant around 6–8 kHz and 15–16 kHz during natural rainfall and explained that large drops in the rain create observable low frequency energy as compared to that of smaller drops. Small raindrops radiate measurable broad-band impact sound and a much higher energy sound of a damped micro bubble oscillation at peak frequencies around 15 kHz [11]. Rain drops of different size splashing on a water surface produce sound that is distinctive and the drop size distribution of the rain can be made. The laboratory experiments on individual rain drops was carried out and it was observed that when the rain contains small raindrops (0.8–1.2 mm diameter); an acoustic signal is present from 13 to 25 kHz. This feature is most apparent when the rain does not have larger water drops present (2.0–3.5 mm diameter), the sound level below 10 kHz is large and there is often a relative peak in the sound spectrum at a frequency between 2 and 5 kHz. If very large raindrops (greater than 3.5 mm) are present, the acoustic signal is very large and extends from 1 to 50 kHz. In all cases, the acoustic signal from the rain is very loud, sometimes as much as 50 dB above the background noise level [12]. Ambient noise measurements were made in the shallow water of Bay of Bengal to investigate the wind dependence of ambient noise. It was found that the correlation between the wind speed and the ambient noise spectrum level was higher at lower frequencies. Further it was observed that the wind generated noise level measured during summer was approximately 8 dB less than that in other seasons [13]. Estimation of ambient noise spectrum influenced by wind speed and wave height carried out for the frequency range of 500 Hz–5 kHz using a Feed forward Neural Network (FNN) was presented. The results reveal that the neural network method is useful in the estimation and interpolation of underwater noise spectrum level and simulation in the considered frequency range [14]. Experimentally it was observed that for underwater impact noise of individual drops of various sizes the frequency of drop impact decreases as the drop size increases (for 2 mm drop impact 8389 Hz, for 4 mm drop 7733 Hz and for 6 mm drop 5898 Hz) [15]. The present work emphasizes on interpretation of underwater noise spectra of rain on water bodies. Experimental results (time domain and frequency domain) of natural and artificial rains and study of resonating frequencies of artificially generated bubbles of various sizes (1.0–10 mm) on water surface have made it feasible to analyze the rain water spectra completely. These findings are aimed to enhance the understanding of characteristics of rainfall measurements on water bodies.

This research is based on the fact that the rain water spectrum of underwater noise depends on underwater bubble and rain drop sizes. Bubble formation and its noise is a natural phenomenon which occurs on the water surface as well as underwater, however one can hear only water droplet impact and bubble bursting noise. The intensity of underwater bubble noise is higher than that on water surface and is not audible, since it occurs underwater. The mechanism of generation of underwater noise is basically initiated from rain water droplets falling on water surface. When a water droplet makes an impact on water surface, it collapses creating a noise and simultaneously takes air along with it. Once the air is entrapped into water, a cloud of bubble formation takes place. Various other factors such as air velocity, angle of inclination and velocity of falling drops also affect the bubble size but are not taken into consideration here.

2. Experimental procedure

2.1. Bubble size measurement

An 18 cm long measuring ruler, having slightly lower density than water, is placed in floating condition in a water tank (1 m × 1 m × 1 m) making a perfect alignment with the water surface. The minimum size of bubble considered for the experiment is 1.0 mm in diameter as the least count for measurement was 1 mm. Though formation of underwater bubbles of diameter less than 1 mm has been observed, shorter life span of such bubbles makes it difficult for accurate recording and size measurement. During this experiment, nozzles of various sizes (0.1–3.0 mm in diameter) were also used to generate bubbles of different sizes. The nozzle is connected to an air compressor through an air regulator for controlling the airflow rate precisely. For this experiment, the floating bubble's photographs are captured by a Sony – HDR-CX550 (12MP) camera is shown in Fig. 1. These results indicate that bubbles of 2 mm diameter are almost spherical due to their small size and high surface tension, but the same is not the case for bubbles of 4 mm and 6 mm diameters. Bubble of 6 mm size shown in Fig. 1(c) appears as oval shaped, due to their large size and low surface tension. This deviation in size further increases with increase in drop velocity and reaches a