# Simulation of microbubble reconstruction using compressive holography

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## Abstract

Microbubbles (MB) are small sphere of gas enclosed in liquid. Due to their small size and unique properties, MB have been studied extensively for several application such as drug delivery, ultrasound contrast, particle tracking velocimetry, and agriculture. The main parameter for MB is the size distribution, which may varies depending on the use case. Measuring the size distribution in-situ is often difficult. The aim of this study is to develop a novel method for determining the individual size and overall size distribution of MB suspended in water. The proposed method is based on compressive holography. First, digital hologram of MB is captured using digital camera. Then, MB at multiple z-planes are reconstructed by solving an underdetermined inverse problem. The key idea is to exploit the sparsity of MB in the suspending medium and applying the compressive sensing approach to find the optimum solution. The feasibility of proposed method is demonstrated via optical simulation. Based on the simulation, the individual MB can be reconstructed and the overall size distribution has good agreement with ground truth. In conclusion, the proposed method has huge potential to be utilized for in-situ MB size measurement.

## 1 Introduction

In recent years, microbubbles (MB) have been actively studied for various applications. Early exploration of MB's potential in medical field starts as drug carrier and ultrasound contrast[1]. The versatility of MB quickly leads to applications in other fields. In agriculture, MB can be utilized to deliver oxygen to plant roots thus producing larger yields[2]. Another recent example of MB application is improving the diesel engine performance[3].

By definition, MB are small sphere of gas, (e.g., air) that are enclosed in liquid (e.g., water, oil). In general, the diameter of microbubble is defined to between 1µm to 50µm. One of the key parameters for microbubble is the size distribution. For example, when used as ultrasound contrast, the modulation characteristic will depend on the microbubble size.

The common approach for measuring MB size is by using particle analyser. The underlying technology uses electro-impedance volumetric zone-sensing, optical microscopy or laser diffraction[4].

Measuring MB size distribution in-situ can be a difficult process. This is because particle analyser is usually bulky and problematic to be integrated with the main system. Thus, MB size usually measured ex-situ which might give different result. Satake et.al.[5] proposed a method to determine the 3-D coordinate and size of MB using digital holography. The method was developed for particle velocimetry, where each MB displacement is used to calculate the fluid velocity field. In their proposed method, the digital hologram of MB is captured and backpropagated to find the location and size of individual bubble, which is determined by the existence of two intensity peaks. Contrary to conventional microscopy, the method requires no lens thus much easier to be integrated into other system. Moreover, since the underlying principle is based on phase i.e., refractive index measurement, the image contrast is not affected by transparent nature of MB. Unlike laser diffraction measurement that estimate the particle size based on the speckle pattern, digital holography can reconstruct particle down to individual level.

Despite having these advantages, determining the accurate MB size in digital holography is still a challenging problem. This is because the reconstructed planes will contain diffraction pattern from other out of focus planes. Thus, the measurement accuracy will highly depend on severity of the noise. Reconstructing correct 3-D voxels from 2-D hologram can be considered as underdetermined inverse problem, because the number of unknowns variables (voxels) are much greater than the known values (hologram).