Bubble Analyser — An open-source software for bubble size measurement using image analysis

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Abstract

Bubble size distribution (BSD) is a factor that is well known for influencing the performance of many industrial processes, such as froth flotation. The most commonly used method for measuring bubble size consists of processing photographs of the bubbles. However, the source code of the algorithms for performing the image processing has been seldom published. This article addresses the above by presenting a comprehensive open-source software for processing images of bubbles, allowing researchers to quantify BSD. This software – Bubble Analyser – includes a standard image processing algorithm that was tested against manually segmented images, showing errors under 5% in the calculation of the Sauter mean diameter, the most common descriptor of BSD. Additionally, Bubble Analyser has been designed to easily incorporate new segmentation algorithms developed by other researchers, in order to expand the software capabilities, allow for algorithm comparisons, and foster collaboration in research.

Keywords: Image processing, open source software, bubble size distribution, froth flotation

1. Introduction

Gas bubbles are used in several industrial applications in order to mix a gaseous phase in a liquid-gas or a liquid-gas-solid system. Most of these applications directly depend on the gas surface available, either for mass transfer reactions or for particle attachment due to hydrophobicity. Consequently, it is important to measure and control the bubble size distribution (BSD) as it is inversely related to surface area.

Image analysis is the most widely used method for bubble size quantification and analysis, due to its simplicity, accuracy and relatively low intrusion in the operation of the reactor (Chen et al., 2001; Hernandez-Aguilar et al., 2002). For a thorough review of the different techniques used to measure BSD, the reader is referred to Junker (2006).

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In the case of froth flotation, measuring and controlling key variables can have important benefits on performance (Quintanilla et al., 2021). Since bubble size can be controlled in flotation by the addition of frothers and varying operating conditions (Mesa & Brito-Parada, 2020), the use of a viewing chamber to collect and photograph bubbles has become a common practice (Panjipour et al., 2021).

Designs as the McGill bubble viewer (Chen et al., 2001; Hernandez-Aguilar et al., 2002) and the Anglo Platinum Bubble Sizer (Amini et al., 2013) are based on this principle and have become the standard technique for bubble size measurement. Building a bubble viewer is relatively simple and low-cost, especially considering that many authors have published detailed drawings of the apparatus including its dimensions (Hernandez-Aguilar et al., 2002). The process of photographing and analysing the images, however, has been less discussed.

Once the photographs have been obtained, the image analysis is not a trivial process and many authors tend to develop their own in-house codes for bubble size measurement, usually without publishing the code itself (Panjipour et al., 2021). Novel image processing techniques (e.g. Poletaev et al. (2020); Vinnett et al. (2018)), have not been yet widely incorporated by researchers and practitioners, probably because their respective source codes have not been published.

The aim of this work is to share a comprehensive, flexible and user-friendly open-source image analysis software for bubble size measurement, with no fees for use and modification under a GNU General Public License. The image processing algorithm implemented in the app was tested and compared against manual segmentation for three experimental cases in a two- and three-phase system.

2. Experimental

2.1. Bubble Viewer apparatus

Bubble photographs were obtained using a bubble viewer apparatus based on the McGill Bubble Viewer (Hernandez-Aguilar et al., 2002). The apparatus, camera configuration and sampling operation used in this work were the same described in Mesa & Brito-Parada (2020).

2.2. Bubble Analyser software

An open-source software—*Bubble Analyser*—has been developed using Matlab's App Designer. The software was also compiled and built as a separate executable that does not need Matlab to run, with the caveat that the use must be for research and non-commercial. The source code is published in a public GitLab repository under a GNU General Public License[1].

The use of a public online repository allows anyone interested to not only download the source code, but also collaborate and contribute to the project. The main aim for this approach is to foster collaboration

[1]https://gitlab.com/frreyes1/bubble-sizer

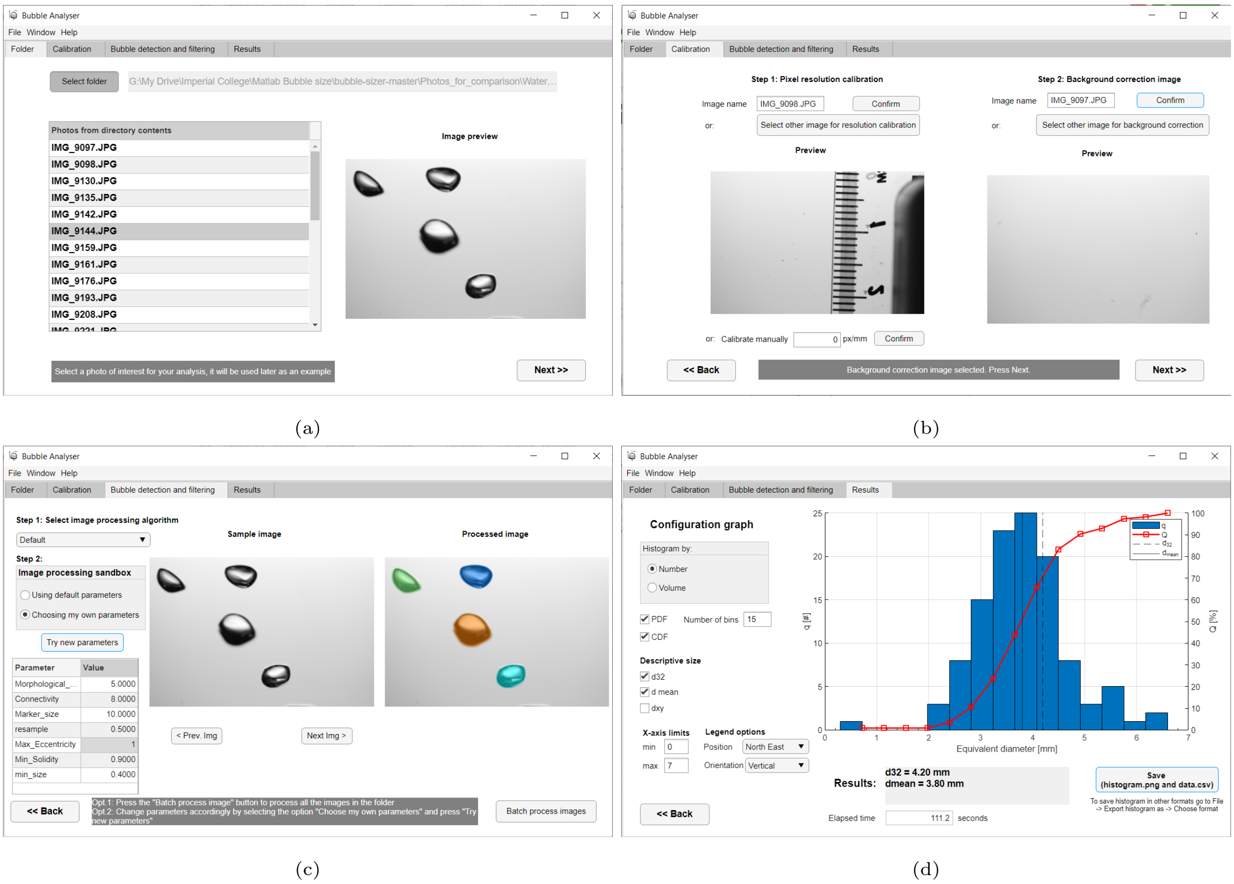


Figure 1: Screenshots of *Bubble Analyser* showing all steps: a) selection of the images, b) calibration, c) image processing and d) results visualisation.

within the mineral processing community, so other researchers can include their already published image processing algorithms. Developers can define their own processing code for bubble diameter measurement, as *Bubble Analyser* has been programmed to send the required information to those algorithms and receive back the results so they can be shown within the app. Developers are also given the possibility of showing and editing those algorithm's tuning parameters within the user interface of *Bubble Analyser* (Figure 1c). A manual with the instructions for *Bubble Analyser* app installation and usage is available in the supplementary material of this manuscript. *Bubble Analyser* comes with a default image processing algorithm for those researchers who need to measure BSD but might not have a background in image processing.

2.3. Image analysis algorithm

Bubble Analyser's code includes a Matlab routine based on a sequence of actions for segmenting bubbles, separating them from one another and applying filters to remove unwanted bubbles from the analysis. The algorithm initially requires a calibration step (Figure 1b), in which the user needs to provide the image resolution (in number of pixels per mm). This calibration can be done by either entering the resolution manually or analysing a photograph with a 1 cm scale object (e.g. a ruler). The algorithm also benefits from the user including a background correction image, this is an empty image (no bubbles) that helps the image processing algorithm process the unavoidable spatial differences of lighting in the photographs. Providing this information to the algorithm allows it to correct for these illumination differences when segmenting the bubbles from the background.

Table 1: Tuning parameters used in *Bubble Analyser* with the default algorithm described in Section 2.3.

Parameter	Water	Frother	Three-phase
Size of closing element, px	5	3	3
Neighbourhood size, #	8	8	8
Marker size, px	10	2	2
Re-sample, [0,1]	0.5	0.5	1
Maximum eccentricity, [0,1]	1	0.65	0.85
Minimum solidity, [0,1]	0.9	0.9	0.9
Minimum bubble diameter, mm	0.4	0.095	0.106

Due to the 2D nature of photography, bubbles will overlap and will be segmented as a unit, that will later be measured as a big bubble instead of two smaller ones. Watershed algorithms are commonly used to perform the task of separating overlapping objects (Gonzalez & Woods, 2002). Because bubbles' size can vary with operating conditions, *Bubble Analyser* allows the user to change a parameter (marker size) to determine the best value for the user's data.

A final step is used to filter out some bubbles. The watershed algorithm for separating overlapping bubbles can sometimes fail to do so and some bubbles do not appear wholly in the photograph. Those groups of bubbles can be removed based on their shape and/or size. *Bubble Analyser* comes with a filter for Solidity and Eccentricity (Gonzalez & Woods, 2002).

After those steps, all of the bubbles' equivalent diameters (diameter of the circle with the same area as the bubble) are calculated and plotted as a distribution (see Figure 1d). *Bubble Analyser* allows the user to plot these distributions on a by-number or by-volume base. Descriptive parameters such as the Sauter mean diameter ($d_{32} = \frac{\sum d^3}{\sum d^2}$) (Riquelme et al., 2013) can also be calculated and plotted. The graphs and raw data can then be exported as image/PDF and CSV files, respectively.

A comparison of the default algorithm against manually segmented photographs for water, two-phase system (Mesa & Brito-Parada, 2020) and three-phase system (Mesa et al., 2020) are presented and discussed below.

3. Results

3.1. Bubble Analyser validation

A sub-sample of random photographs depicting a total of at least 100 bubbles, generated under different conditions, were manually analysed and compared with the results obtained with the automatic algorithm. The conditions studied were: a) bubbles generated in tap water, b) bubbles generated in water with frother (10 ppm of DF250) at a dose higher than the critical coalescence concentration (CCC), and c) bubbles generated in a three-phase system (quartz was used as solids, with a particle size ranging between 75 µm and 150 µm).

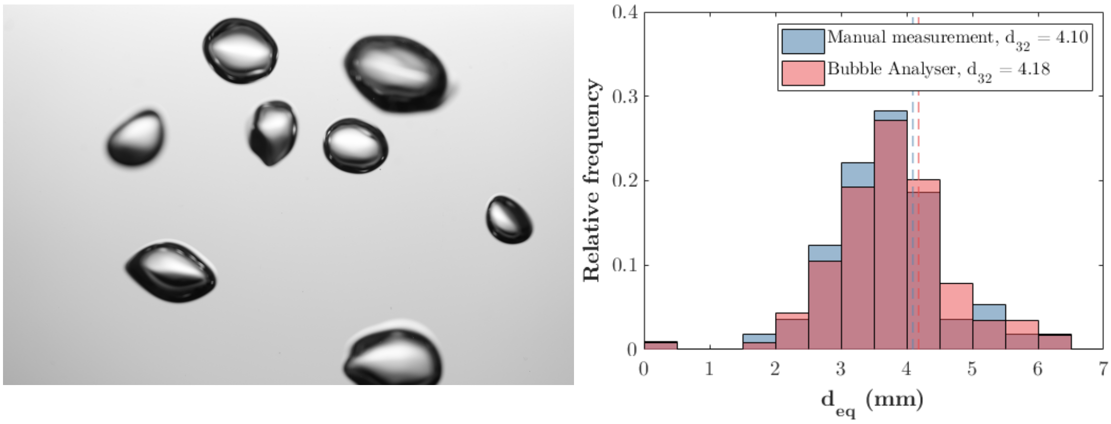
Each bubble was manually delimited using the open-source image analysis software Fiji (Schindelin et al., 2012), in order to estimate the actual BSD. The area of each delimited bubble was then used to calculate the equivalent diameter. It is worth noting that the manual analysis of bubbles using Fiji is very precise, but it is time consuming. The analysis of only one photograph using this method can take approximately 30 minutes, depending on the number of bubbles, complexity (overlapping and or blurry bubbles) and user experience.

These manual results were compared with those obtained using *Bubble Analyser*, as shown in Figure 2. *Bubble Analyser*'s algorithm tuning parameters used for each condition are detailed in Table 1 and can serve as a reference value for users.

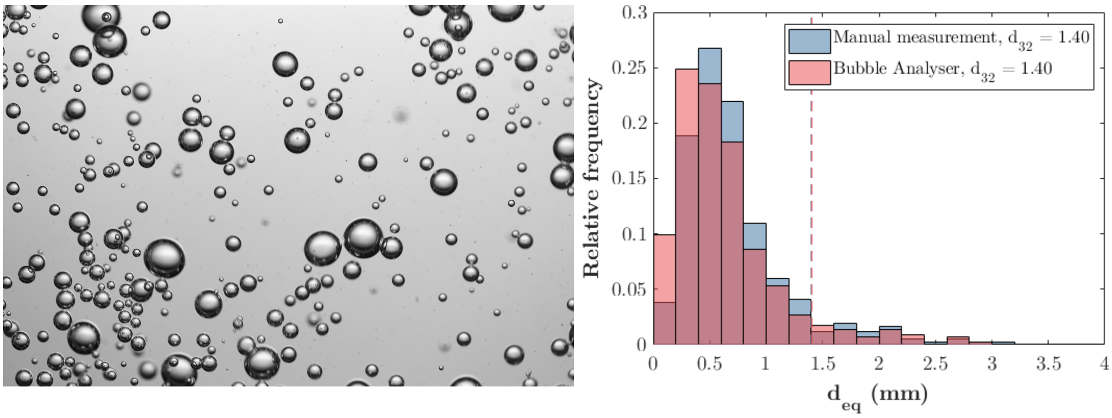
Table 2: Comparison of the BSDs obtained manually using Fiji and automatically using *Bubble Analyser*

Condition	Software	Sample size	Number of bubbles		d_{32}, mm	
			Value	Error, %	Value	Error, %
Water	Fiji	26	113	0.89	4.10	1.95
	Bubble Analyser		114		4.18	
Frother	Fiji	3	419	8.35	1.40	<1
	Bubble Analyser		454		1.40	
Three-phase	Fiji	3	427	-8.20	1.17	5.13
	Bubble Analyser		392		1.23	

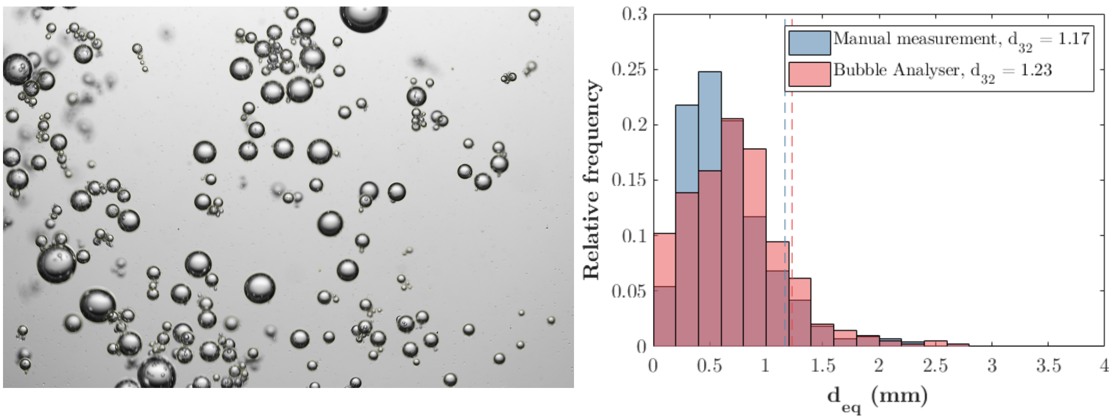
Results show that *Bubble Analyser* generates similar results to those obtained using the manual methodology, as summarised in Table 2. The relative error for the Sauter mean diameter between manual segmentation and the automated process via the app is less than 2% for the two-phase systems and close to 5% for the more complex three-phase system. The amount of bubbles identified in the last two cases are considerably different, with a relative error of more than 8%. This can be due to the current algorithm



(a) Bubbles in water



(b) Bubbles in water with frother



(c) Bubbles in three-phase system

Figure 2: Comparison of the BSDs obtained manually using Fiji ("real bubble size" in blue) and automatically using *Bubble Analyser* (in red), obtained in a) water, b) water with frother over the critical coalescence concentration CCC, and c) in a three-phase system. Photographs are from experiments in Mesa & Brito-Parada (2020) and Mesa et al. (2020).

having troubles dismissing out-of-focus bubbles and due to the lower limit introduced in the three-phase system. This limit is used to prevent the identification of particles as possible bubbles.

4. Conclusions

The present article introduces *Bubble Analyser*, a comprehensive open-source software for image analysis designed for measuring BSDs in flotation cells and other aerated reactors. *Bubble Analyser* is aimed for both, researchers experienced in image processing and those who are not. The software is available in a collaboration-oriented platform (GitLab) and has an interface that allows the use of user-defined algorithms. *Bubble Analyser* also incorporates its own image processing algorithm, which has been here validated under three different operating conditions, including a three-phase system. The algorithm was tested and validated against manually segmented images, with results showing relative error between manual and automated segmentation of 5% or less.

The present work aims to foster open collaboration in the minerals processing industry and image analysis community, especially in the field of software development, by providing an open platform for researchers to measure BSD, share their algorithms and have a base case to benchmark against.

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