Detection of densely dispersed spherical bubbles in digital images based on a template matching technique

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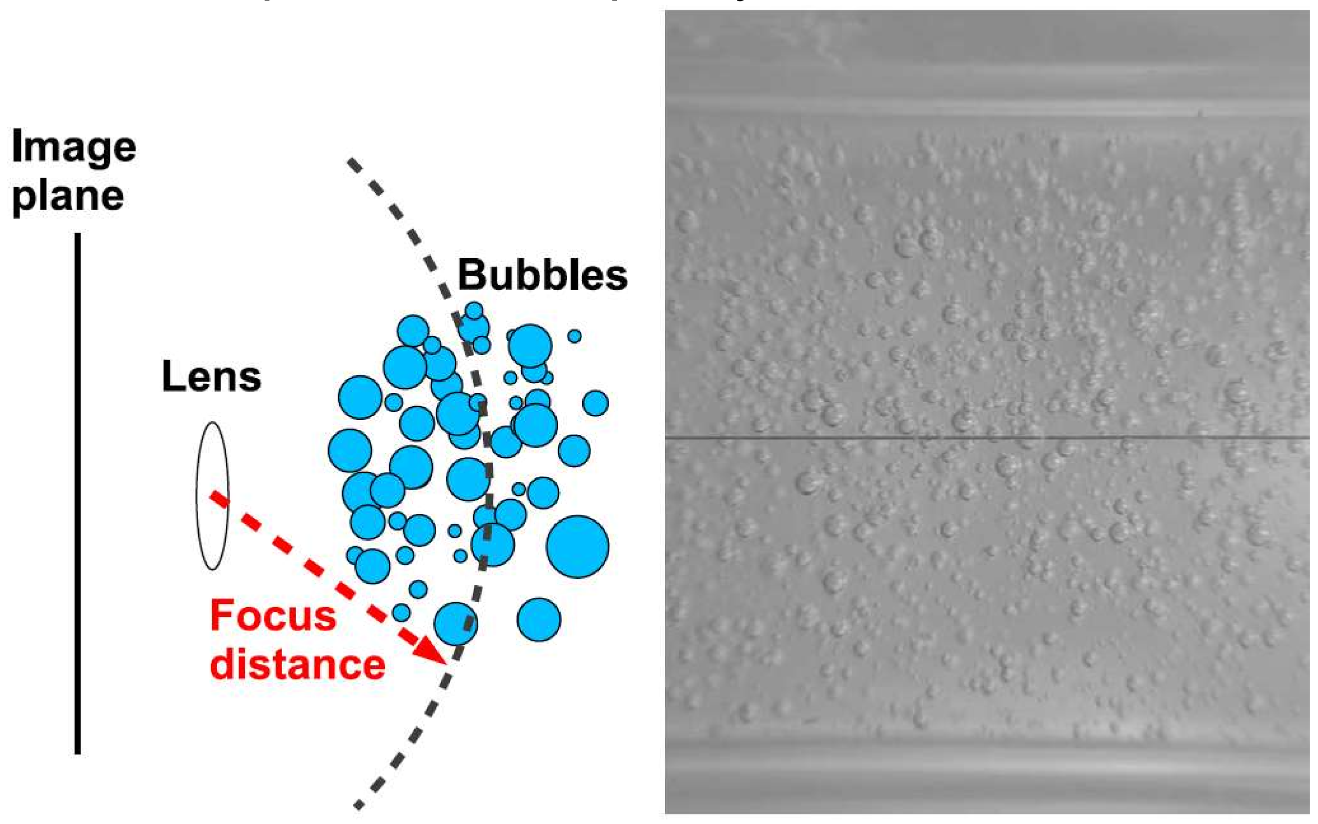
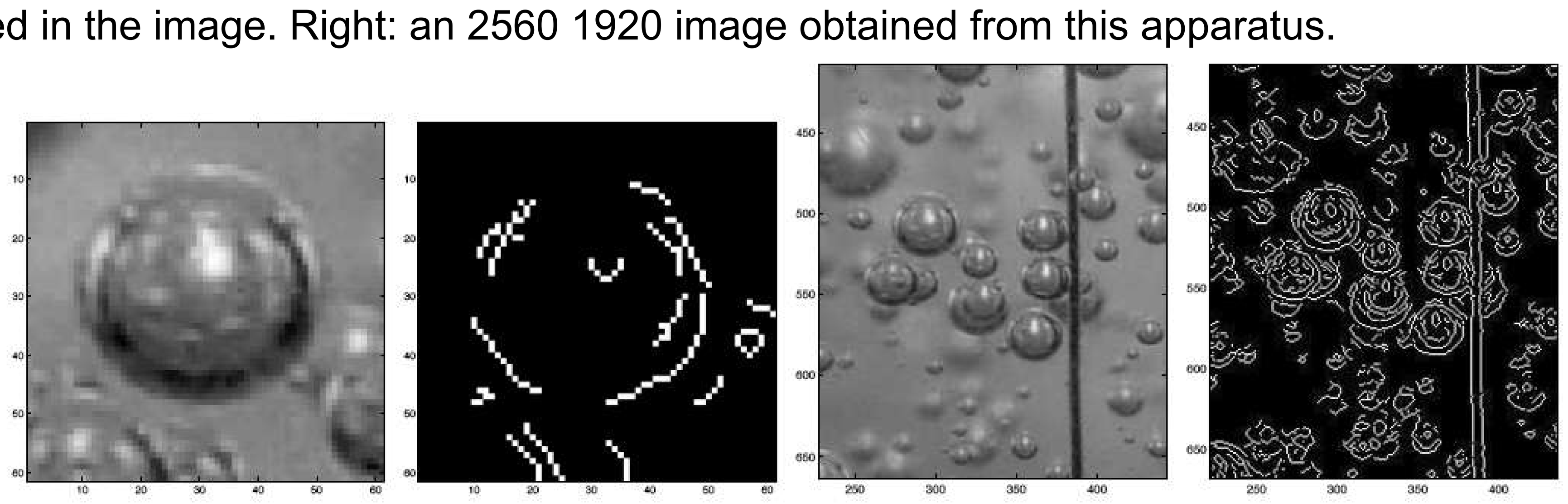
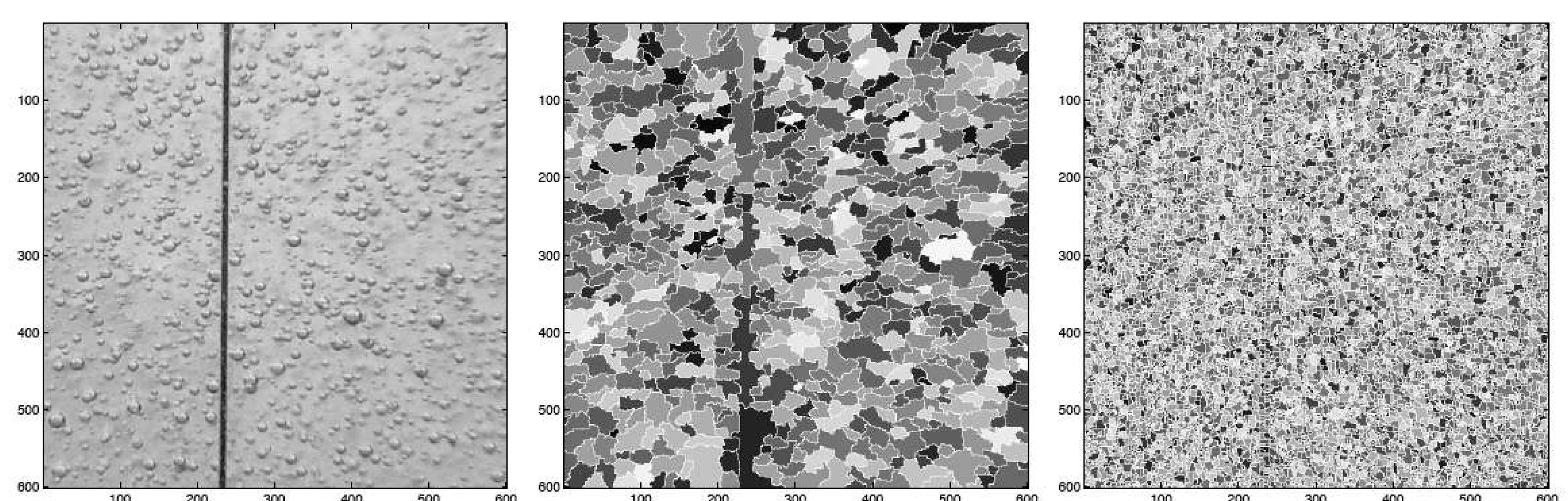
Abstract This work describes a, single-camera, optical bubble-measurement-system (BMS), which features a template-based bubble detection method. The motivation for the proposed approach is the poor performance of conventional methods towards bubble detection in dense dispersions of bubbles. The, poor, performance of such conventional approaches is reviewed, demonstrated and explained. The proposed approach utilizes templates to increase bubble-detection robustness and an image scale-space to detect bubbles independently of their size. In addition, this scale-space is utilized to estimate the level of focus of each depicted bubble and, thus, extract only bubbles that are focused in the image. The size of these, focused, bubbles can be then directly estimated from their size in the image since their distance is known (focus distance). Finally, future word regarding the usage of the proposed approach to bubble detection in the tracking of bubbles is discussed along with technical and experimental improvements that concern the optimization of the system's performance, in terms of precision and computational complexity.



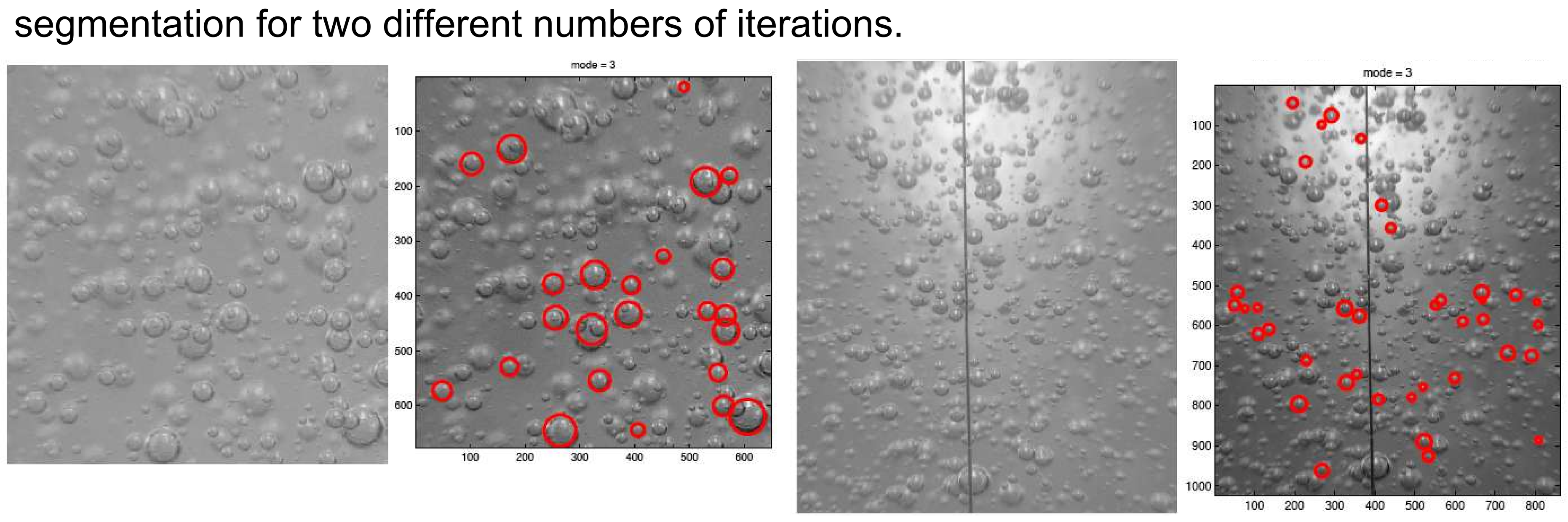
Left: the bubble measurement apparatus; only bubbles at the focus distance will appear focused in the image. Right: an 2560 1920 image obtained from this apparatus.



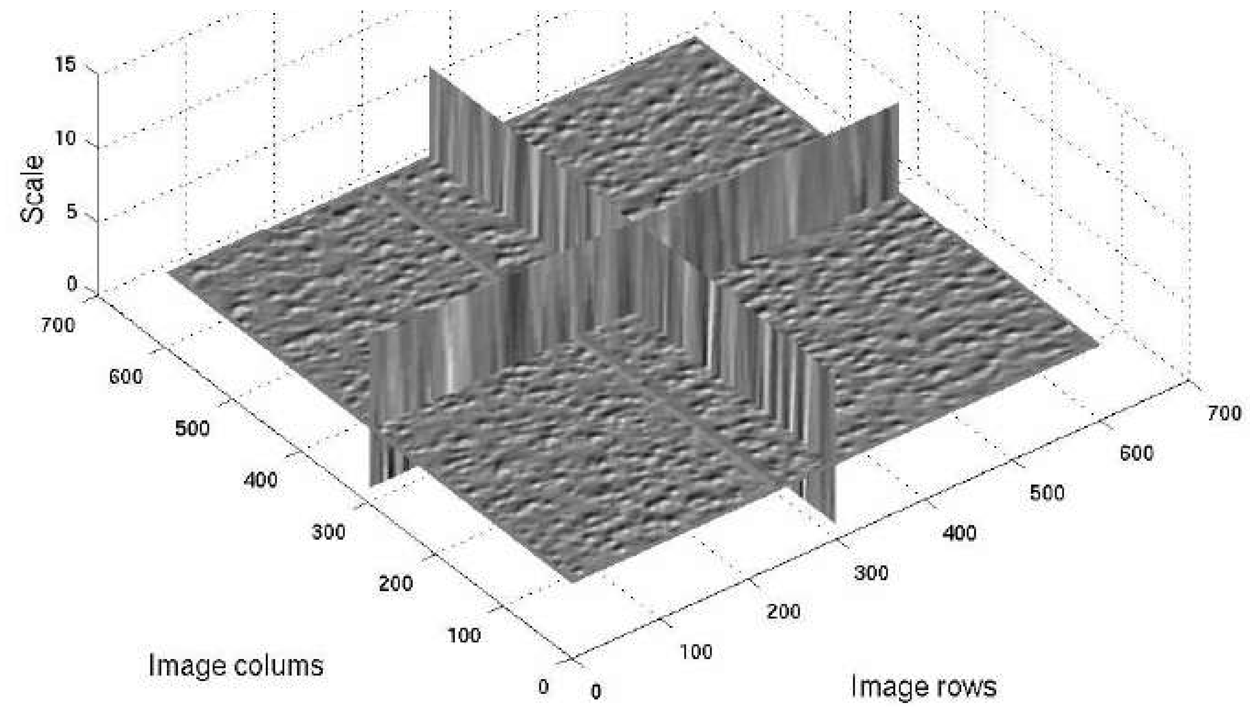
Details of two original and edge images. Reflections, occlusions, shadows, and highlights give rise to complex edge images that are difficult to directly use to estimate bubble shape.



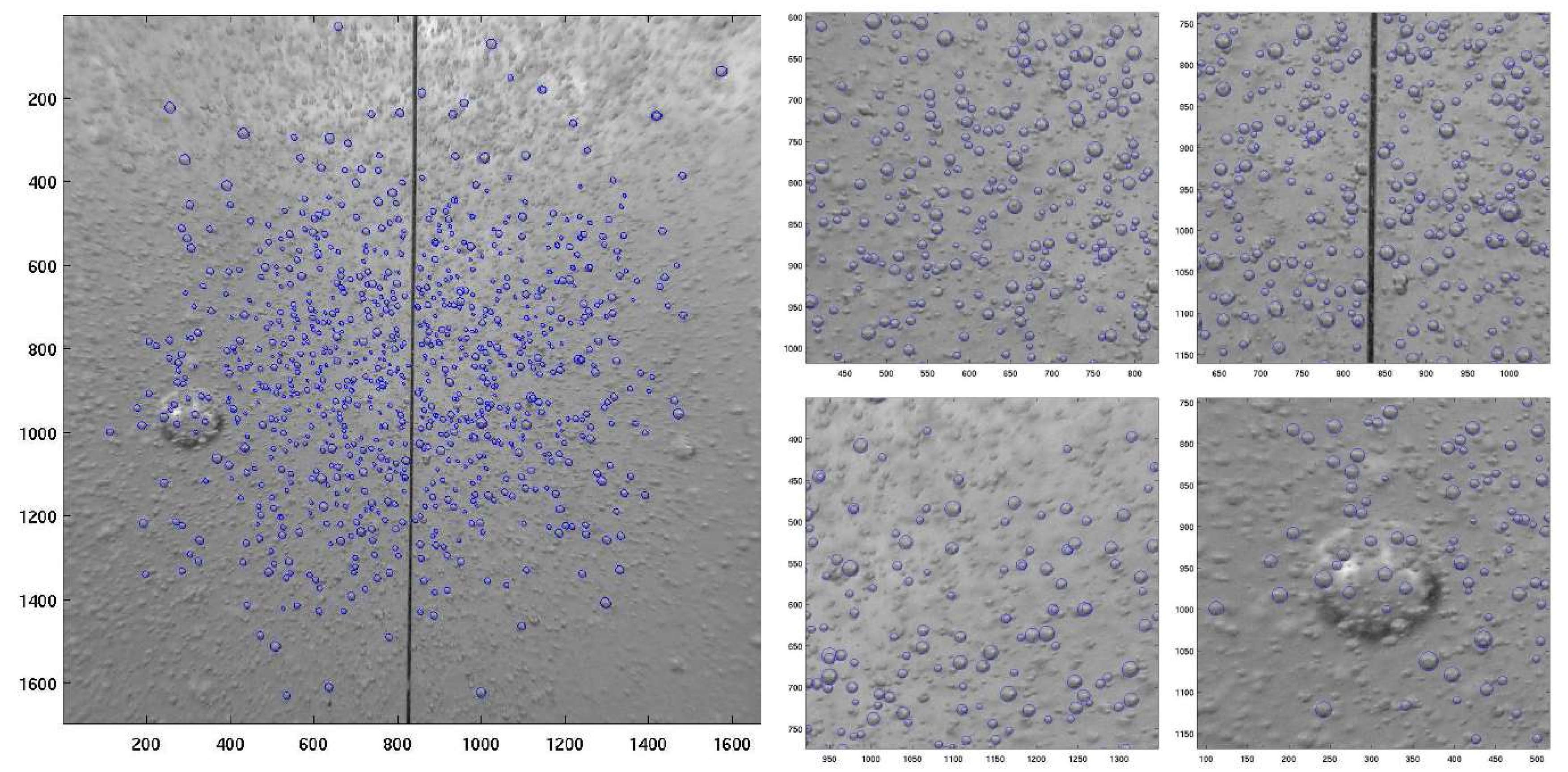
As a result, typical contrast-based segmentation techniques do not suffice for bubble-detection purposes. The images above, show an original image and its watershed segmentation for two different numbers of iterations.

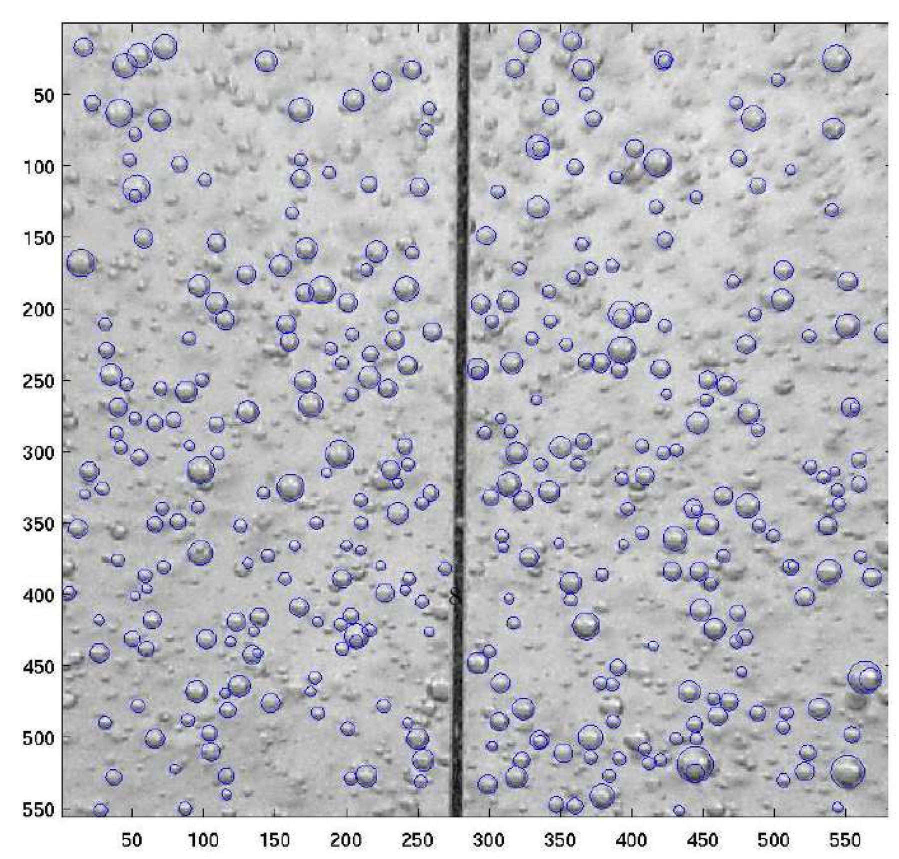


Similarly, poor performance is encountered when the, conventional, Hough circle-detection method is employed. The reasons are the poor occurrence of edges around the outline of bubbles and the dense dispersion of bubbles in the image. This latter factor causes the detection of spurious bubbles which are formed by (and in-between) the outline segments of multiple neighboring bubbles. In order to eliminate such spurious detections a high voting threshold is required from the Hough method. However, such a high threshold eliminates valid bubbles as well. The figures above demonstrate the Hough circle detection method.



Employing template matching includes the manual (or automatic, using the Hough method) selection of a few bubbles in the image and their usage as prototypes to, automatically, detect the rest. The process of template matching for a single prototype is as follows. The (small) image patch is exhaustively compared, as to visual similarity, with all possible (overlapping) image neighborhoods. The similarity metric used is the Normalized Cross Correlation of the image intensity values. To detect bubbles independently of their size, the selected prototype is iteratively resized, in order to evaluate occurrences of the prototype in a wide range of scales. The normalization of cross correlation facilitates the detection of prototypes despite global image intensity (brightness/contrast) changes. In the figure above the similarity space across a range of scales for an image is shown, with grayscale values being linearly mapped to similarity values. To avoid detecting multiple (overlapping) matches per bubble, the highest scorring local maximum across scale for each image pixel is selected. The above procedure is repeated for each prototype and the results (detected bubbles) concatenated into a data structures. However, since a single bubble may be detected by usage of multiple prototypes, this data structure is processed in order to eliminate multiple occurrences of the same bubble.





The images above and on the left demonstrate the performance of the proposed method by marking the detected (focused) bubbles. As it can be observed, the method not only discriminates between focused and unfocused bubbles but is robust against bubble overlap, which is typical in dense dispersions.

Improvements of this method that are warranted in future work are to:

- refine focus estimation based on edge-focusing of the image gradient
- obtain invariance to rotation, by considering all 360 bubble rotations (in case that the light source is so close that bubbles exhibit their shadows at different eccentricities along their circumferences).
- conserve computational power by performing a coarse-to-fine (resolution-wise) search for the NCC local maxima.
- compensate for the radial distortion of the lens to improve detection and measurement precision.

The method described in this work is to be utilized in the tracking of bubbles in image sequences. At each frame bubbles will be detected using this method and corresponded to those in the next frame. Derivation of the bubble locus with respect to time provides the velocity and acceleration information. However, since new bubbles may entered the observed scene, the detection method is invoked at each time frame. The accuracy of the tracking process is to be enhanced by application of Kalman filtering for motion tracking.

References

[1] N. J. Hepworth, J. R. M. Hammond, and J. Varley. Novel application of computer vision to determine bubble size distributions in beer. Journal of Food Engineering, 61:119-124, 2004. **[2]** I. Leifer, G. Leeuw, and L. H. Cohen. Optical measurement of bubbles : System design and application. Journal of Atmospheric and Ocean Technology, 20(9):1317-1332, 2003. **[3]** T. A. Kowalewski, R. Trzcicski, A. Cybulski, J. Pakleza, and M. C. Duluc. Experimental analysis of vapour bubble growing on a heated surface. In 3rd international conference on Transport Phenomena in Multiphase Systems, 2002. **[4]** R. Kulenovic, R. Mertz, P. Schfer, and M. Groll. High speed video flow visualization and digital image processing of pool boiling from enhanced tubular heat transfer surfaces. In 9th international symposium on flow visualization, pages 22-25, 2000. **[5]** T. A. Kowalewskia, J. Paklezab, and A. Cybulskia. Particle image velocimetry for vapour bubble growth analysis. In 8th International Conference Laser Anemometry Advanced and Applications, 1999. **[6]** Y. Zhu, B. Carragher, and C. S. Potter. Automatic particle detection through efficient hough transforms. IEEE Transactions on Medical Imaging, 22(9):1053-1062, 2003. **[7]** S. B. Harvey, J. P. Bestz, and W. K. Soh. Vapour bubble measurement using image analysis. Measurement Science and Technology, 7(4):592-604, 1996. **[8]** T. Lindeberg. Edge detection and ridge detection with automatic scale-selection. International Journal of Computer Vision, 30(2):117-156, 1998.