Automated Computer Vision Approach for Analysis of Numerical and Experimental Detonation Cellular Structures

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Combustion via gas-phase or liquid spray detonation waves holds promise for developing advanced and highly efficient propulsion technologies for aerospace applications [1]. However, detonations also pose significant safety risks [2], underscoring the necessity of reliable numerical modeling techniques to accurately replicate and predict real-world detonation behavior.

Although multidimensional simulations of gas-phase and spray detonations are prevalent, validating their accuracy remains challenging. A critical aspect of such validation involves precise measurements of detonation cell sizes obtained from soot foil images. Currently, manual cell-size measurements can lead to errors exceeding 50%. Existing automated methods [3-5], while promising, still suffer from limited accuracy, potential bias and can be time-consuming. Consequently, precise measurements of the detonation cell size remain very challenging.

To address these limitations, we propose a novel automated approach employing advanced computer vision techniques to measure and analyze detonation cell sizes. The proposed framework comprises four key steps: (1) image preprocessing, (2) automated contour detection, (3) parameter optimization, and (4) detailed statistical analysis. For all tested cases, this framework achieves relative errors under 10% for regular and approximately 17% for irregular numerical soot foil patterns. Additionally, validation using experimental soot foil data illustrates the capability of our method to provide comprehensive statistical insights into detonation cell structures across various experimental channel sections.

Our method aims to establish a standardized, objective, and rapid analysis process for soot foil measurements. Future research will focus on extending the applicability of this approach to a wider range of numerical and experimental soot foil images.

References

[1] Wolanski P. Detonative propulsion. Proceedings of the Combustion Institute. 2013;34(1):125-158.
[2] Eidelman S and Burcat A. Evolution of a detonation wave in a cloud of fuel droplets. I - Influence of igniting explosion. AIAA Journal. 1980;18(9):1103-1109.
[3] Sharpe GJ and Radulescu MI. Statistical analysis of cellular detonation dynamics from numerical simulations: one-step chemistry. Combustion Theory and Modelling. 2011;15(5):691-723.
[4] Shepherd JE, Moen IO, Murray SB and Thibault PA, "Analyses of the cellular structure of detonations" in Symposium (International) on Combustion, (The Combustion Institute, Pittsburgh, 1988), pp. 1649-1658.
[5] Lee JJ, Garinis D, Frost DL, Lee JHS and Knystautas R. Two-dimensional autocorrelation function analysis of smoked foil patterns. Shock Waves. 1995;5(3):169-174.