An Automated Particle Identification and Analyzation Software for PIV Images

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ABSTRACT

The time to process large PIV data sets can be expensive, and the resultant velocity fields are a strong function of the quality of the particle images used. For new and even experienced users of PIV, determination of the quality of a particle image data set can be challenging and time-consuming, especially for a large number of data sets. This is compounded by new high-speed camera systems that can collect terabytes of data quickly. A software tool is described here that allows the user to make informed decisions on the general quality of the data sets and what pre-processing image data steps are needed. The software provides statistical feedback on such parameters as particle count, particle size, and particle intensity for not only a single image but also a complete data set. Using this software allows the user to make informed decisions and generate and document the quality of the data collected. Based on this, a robust PIV processing algorithm can be developed.

1. Introduction

Particle Image Velocimetry (PIV) has been used in fluid mechanics research for its unique ability to monitor and analyze particle motion in a fluid , providing insights into complex flow structures [1]. The reliability of PIV analyses relies on the precise assessment of particles within PIV images, a fundamental step that affects the quality of velocity measurements [1]. Conventional techniques like visual inspection or basic thresholding face limitations in detecting particles accurately, specifically in scenarios marked by noise or densely populated particle fields [2]. In response to these challenges, a MATLAB-based approach is introduced for automated identification and characterization, streamlining data validation and quality control by conducting preliminary analyses of full datasets [3].

Capturing high-quality raw PIV images is important but challenging, due to various noise sources such as optical imperfections and background interference [4]. Understanding and controlling both imaging hardware and software processing are essential for producing accurate PIV analysis

of complex flows [5]. Several critical metrics, including particle image quality, density, seeding quality, sharpness, and considerations regarding particle size and number, are essential for assessing the suitability of raw particle images for effective PIV processing [5]–[7]. Achieving well-defined, distinguishable particles is fundamental to PIV accuracy, and the proposed methodology emphasizes the importance of these metrics in fluid mechanics research [8].
The efficient particle identification and characterization methodology introduced, represents a potential advancement in fluid mechanics research, specifically for large-scale PIV analysis. By automating and standardizing the identification process, the approach ensures consistent and reliable results across diverse datasets, translating into substantial time savings and enhanced outcomes in cutting-edge PIV research.

2. Software structure

The MATLAB-based method automates particle detection and detailed analysis using advanced image processing and statistical techniques. It offers a user-friendly interface for accurate particle measurement. Users can interactively load images, fine-tune processing parameters, and visualize outputs. The software structure is systematically outlined with a focus on image preprocessing and preliminary particle location. In the image preprocessing stage, an important step involves the application of a boxcar kernel through two-dimensional convolution to the raw image. This process smoothens the image, reduces noise, and enhances the contrast between particles and the background. The algorithmic representation defines the boxcar kernel and its convolution with the image, ensuring optimal parameters for particle identification. Sample images demonstrate the substantial impact of preprocessing on particle visibility and noise reduction.
After the image preprocessing, the software employs a preliminary particle location approach involving manual thresholding to eliminate background noise and identification of local maxima. For an accurate particle location, the operation ensures that only particle intensities are retained. A subsequent step introduces sub-pixel accuracy in centroid location, refining the initial estimates. Inspired by Grier and Crocker's algorithm [9], this process calculates offsets from the brightest pixel to the brightness-weighted centroid within a defined region. The refined coordinates provide a more precise estimation of particle centroids, providing them for precise analysis and characterization in diverse imaging applications by software.
Following particle location, the application conducts a comprehensive analysis of each image in a dataset, enabling in-depth quantitative characterization through statistical analysis. Examined parameters include particle count, size distribution, mean and peak intensities. Per-particle statistics facilitate a detailed assessment of overall data quality and refined characterization of

particle properties within the population. Monitoring variations across parameters can show particle feature uniformity, identify outliers, and support the identification of the potential issues in imaging process. The interactive workflow allows users to adjust these critical parameters, providing visual feedback through graphical and statistical outputs, in order to enhance the accuracy and robustness of the analysis. The toolbox allows exporting a range of quantitative results for further examination, comparison, and documentation, providing a comprehensive PIV image analysis framework.

3. Software functionality

The graphical user interface of the software is shown in **Error! Reference source not found.**. This interface is designed to be user-friendly, allowing new and inexperienced users to easily follow the steps. After the image preview, various preprocessing techniques can be employed to enhance image quality. An important aspect of this preprocessing is intensity thresholding. Users can define a custom intensity threshold to distinguish pixels as potential particles or background. In this example, a threshold of 75/255 is defined via the thresholding window. The intensity histogram features a red line at the threshold value, filtering out pixels below this intensity and removing dark background noises. Importantly, the threshold dynamically adjusts to accommodate particles with varying intensities in relation to their surroundings.

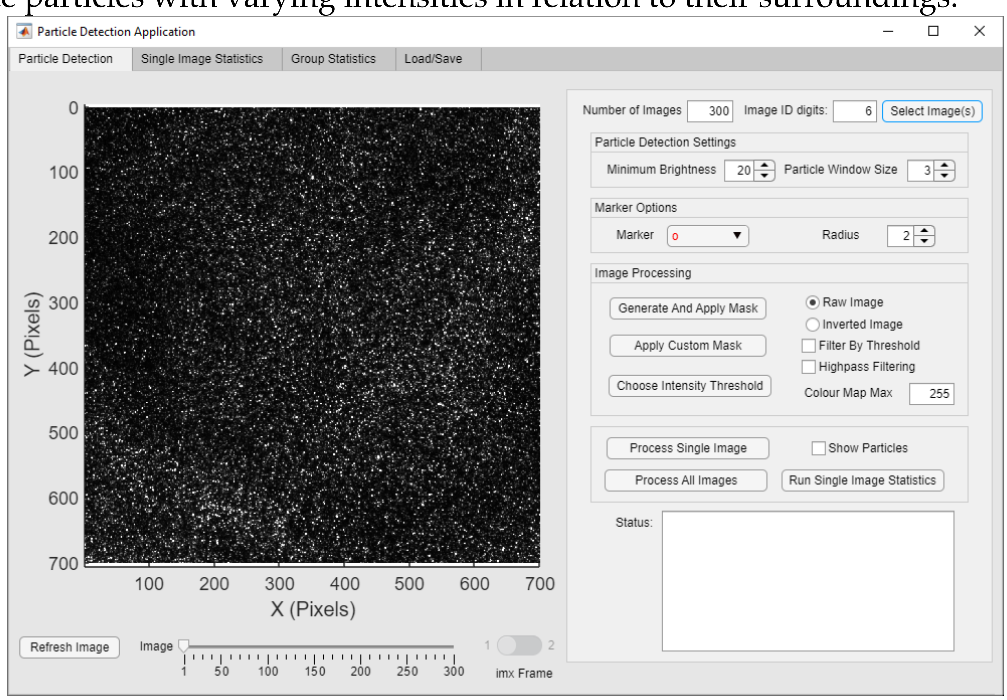

Figure. 1 Graphical User Interface (GUI) screenshot

4. Results

This section presents the results of detection and analysing particle using the designed software. A collection of 300 images are used to show the performance of the software. Detailed information on particle size distribution and intensity characteristics are presented at the end.

The software utilizes advanced algorithms to identify and outline each individual particle within the PIV image with high precision. This capability is visually demonstrated in **Error! Reference source not found.**, where the detected particles are marked onto the original image. The red circles on each particle serve as visual indicators, highlighting the recognition and localization of particles by the software. This visual representation not only enhances the user's understanding of the detection process but also provides a convenient means for assessing the accuracy of particle identification. Users can compare the outlined particles with the features in the original image, allowing for a comprehensive evaluation of the software's performance in capturing the particles of interest. This feature is added to ensure the reliability and precision of the particle detection process, contributing to the overall effectiveness of the software in PIV analysis.

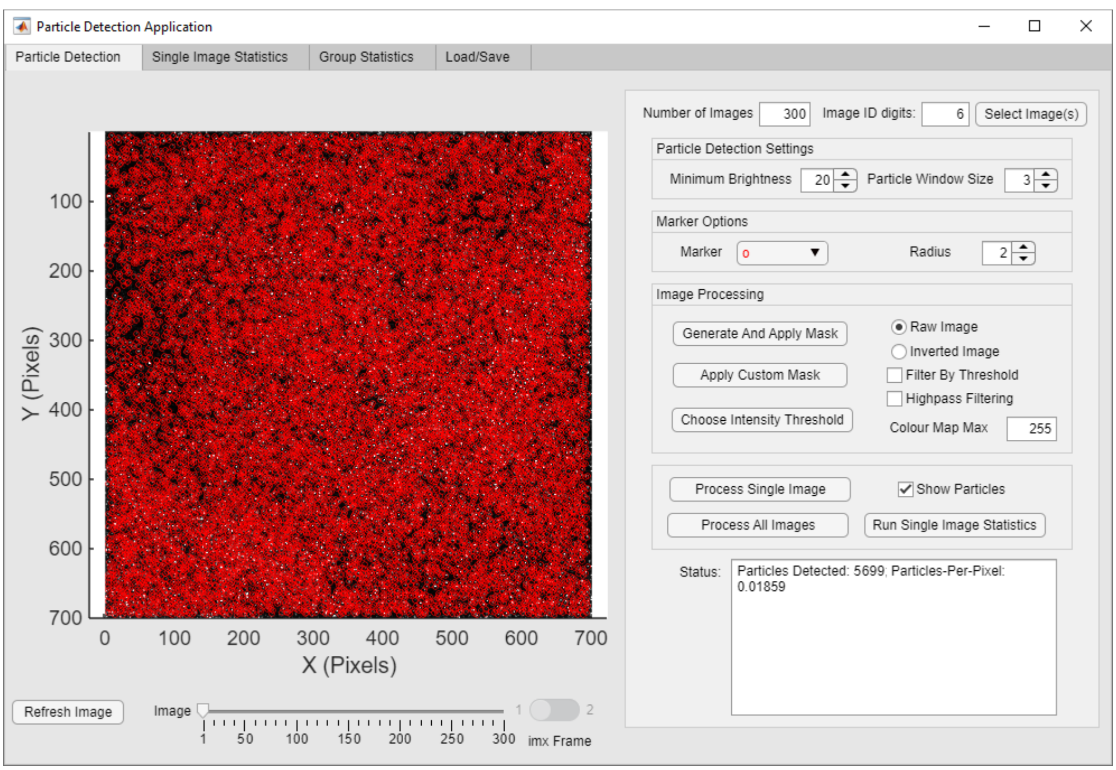

Figure. 2 Particle Detection Results - Displaying the results of the particle detection process overlaid on the original image.

After the particle detection step is completed, the software conducts a statistical analysis of the identified particles. **Error! Reference source not found.** represents a comprehensive view of key particle statistics. The graphs presented in the figure show the variation in the number of particles for each individual frame, particle size, particle intensity, and peak particle intensity. **Error!**

Reference source not found.(a) shows the temporal evolution of particle presence, highlighting any trends or fluctuations. The correlation between the number of particles and their respective sizes is presented in **Error! Reference source not found.**(b), visualizing the size distribution within the dataset. Additionally, the number of particles versus particle intensity and peak particle intensity can be seen in **Error! Reference source not found.**(c), (d) This comprehensive graphical representation significantly enhances the user's ability to interpret and extract information from the statistical analysis, facilitating a detailed review of particle behavior and characteristics.

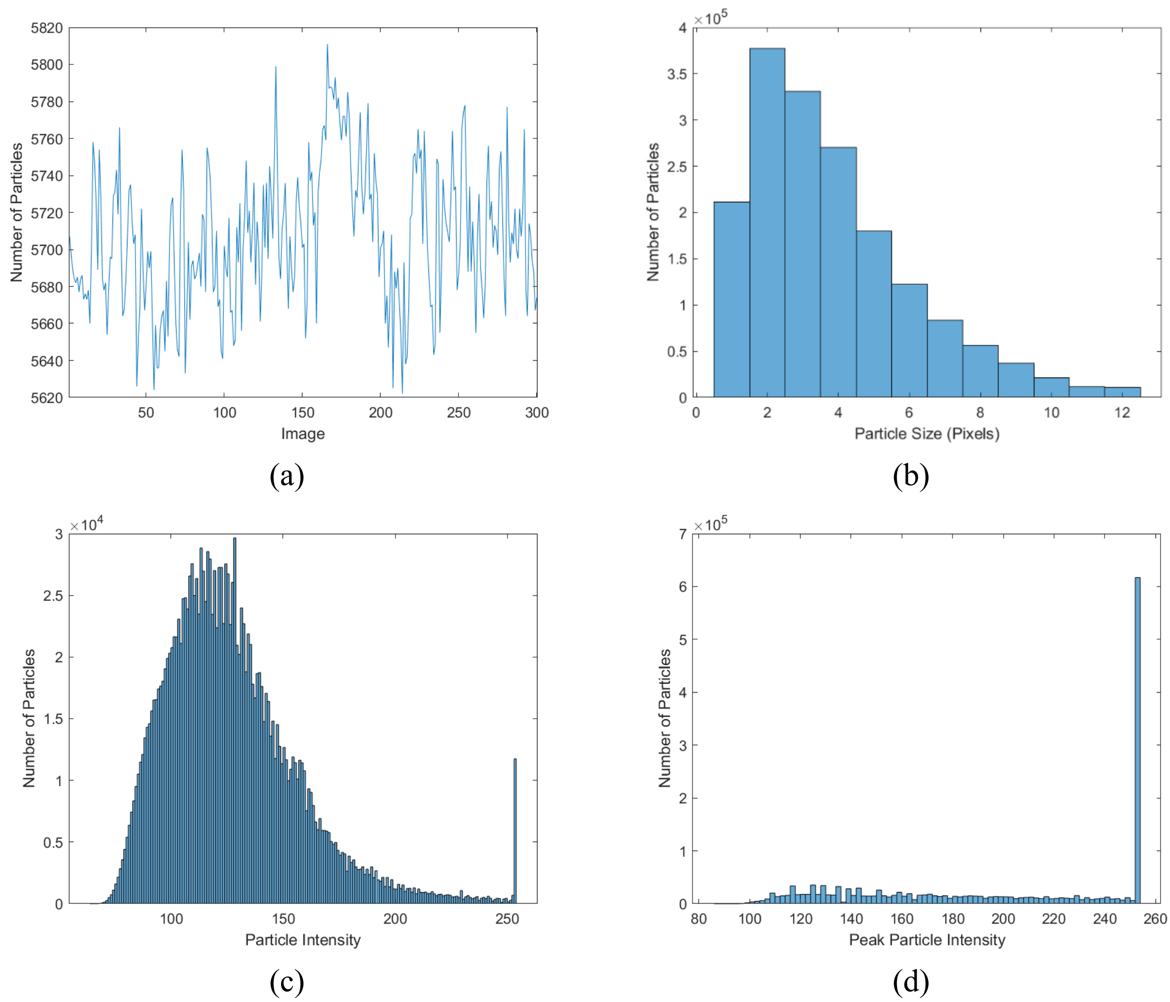

Figure. 3 Particle Analysis Statistics - Displaying multiple measurements including the number of particles, particle size distribution, average intensity, and peak intensity.

5. Conclusion

The proposed software assists in the process of particle identification. A user-friendly interface facilitates its utilization and integration into existing workflows. The software is customized based on specific research requirements and adapted to various datasets. The efficacy and precision of PIV increase by providing statistical analysis feedback.

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