

# USING MATLAB FOR VISUALIZATION OF PLASMA DYNAMICS BY STATISTICAL PROCESSING OF PHOTOGRAPH SEQUENCES

*O. M. Chumak and M. Hrabovský*

Thermal Plasma Department, Institute of Plasma Physics AS CR, v.v.i., Za Slovankou, Prague 18200, Czech Republic

## Abstract

Short exposure photographs capturing the momentary state of the plasma radiation are often used for the primary characterization of discharges. Sequence of such images gives an impression about a variation of radiation intensity in different areas and can be used to describe the fluctuation intensity. This work presents a statistical procedure which produces brightness fluctuation intensity maps. Two realizations of the statistical procedure in Matlab environment are described and compared.

## 1 Statistical processing algorithm

Photographic images are often used as primary characterization of plasma jet [1,2] or flames [3,4]. A space distribution of brightness values gives an idea where more intensive processes take place. While fast shutter image can give information on momentary state of the processes general analysis needs treatment of representative number of images by relevant algorithm. An algorithm of statistical processing for brightness fluctuation analysis was presented in recent publication [5]. It is shown in Fig. 1. And can be summarized as calculation of some statistical parameter (mean, standard deviation, etc.) of local brightness variation and creating of map of its space distribution.

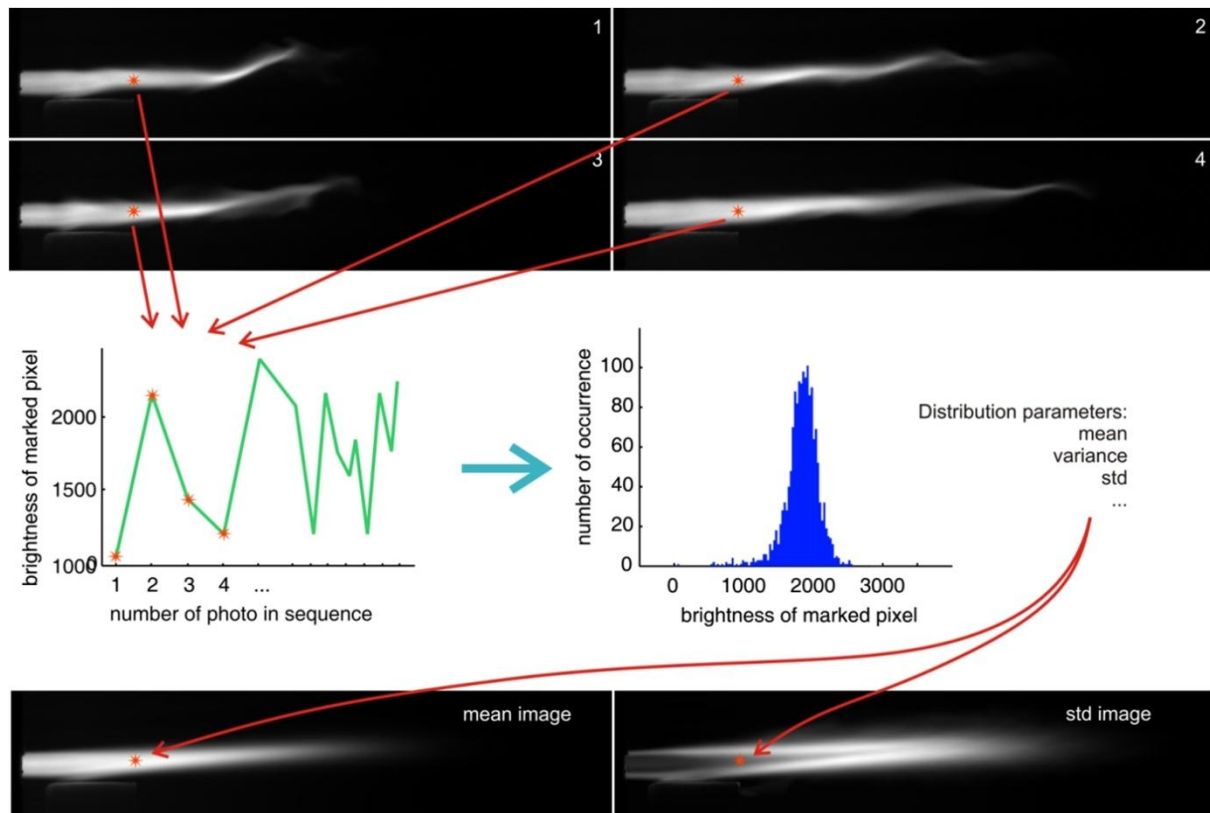


Figure 1: Demonstration of statistical processing of image sequence for brightness fluctuation visualization

The Shannon entropy [5] as defined by the information theory was shown to be the most relevant parameter for stochasticity measurement in [6]. On the base of this term effective parameter

of width of distribution was derived to have the results in convenient linear scale. It can be calculated as follows:

$$W(X) = e^{-\sum_{i=1}^n p(x_i) \ln p(x_i) - \ln n}, \quad (1)$$

This equation and algorithm was coded in Matlab. An example of it usage is demonstrated in the following. In Fig.6 example of histogram of brightness in the jet fringe is shown. Brightness lays in range of values from 88 to 1608. Whole range is divided on 10 regions and the bars have heights [176 70 29 13 7 3 1 0 0 1] and corresponds to values of relative frequency [0.5867 0.2333 0.0967 0.0433 0.0233 0.0100 0.0033 0 0 0.0033]. Entropy and effective width of this distribution are

$$H(X) = -(0.5867 \ln 0.5867 + 0.2333 \ln 0.2333 + \dots + 0.0033 \ln 0.0033) = 1.1861,$$

$$W(X) = e^{1.1861 - \ln 10} = 0.327,$$

which is less than half of maximum fluctuation intensity of 1. Such an calculation is done for every pixel of the images in sequence.

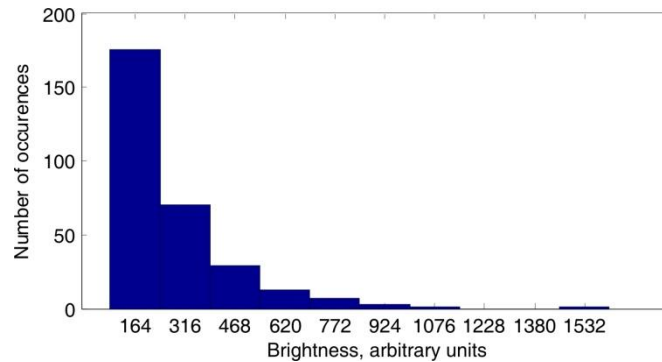


Figure 2: Example of brightness histogram in the fringe of the jet

The only drawback was comparatively high requirements to the memory as the whole image sequence should be loaded into the memory for the processing. If there is sequence of 200 images with the size of 500x1000 and 8 bit gray scale it gives 100 megabyte. It seems that at common conditions modern computers easily meet the memory requirements but it can be obstacle if better resolution and longer sequence is processed. There is also another way to calculate the parameter.

## 2 Fitting of the data set with Pearson family of distributions

Pearson family covers the most famous distributions as normal, gamma, Student's t-distribution and others. It can be used for fitting of distributions of various shapes based on central moments of first, second, third and fourth order. Statistics toolbox of Matlab includes function of generation of random numbers using Pearson distribution family (*pearsrnd*) [6]. Central moments is used here to evaluate the class of the distribution in the Pearson system and then proper random number generator is used. It means that fitted data can be generated based on the central moments of original data distributions. In Fig.3. there are examples of original distribution and a distribution generated by *pearsrnd* function using calculated central moments. Reasonable agreement of the shapes can be seen.

The following procedure is proposed of statistical processing is proposed:

- ☞ Central moments from first to fourth are calculated for original image sequences.
- ☞ For every pixel random numbers are generated by *pearsrnd* function with central moments as parameters.
- ☞ Histogram of the random numbers set is created as in previous method and the effective width is calculated in the same way.
- ☞ The results are mapped and image is generated.

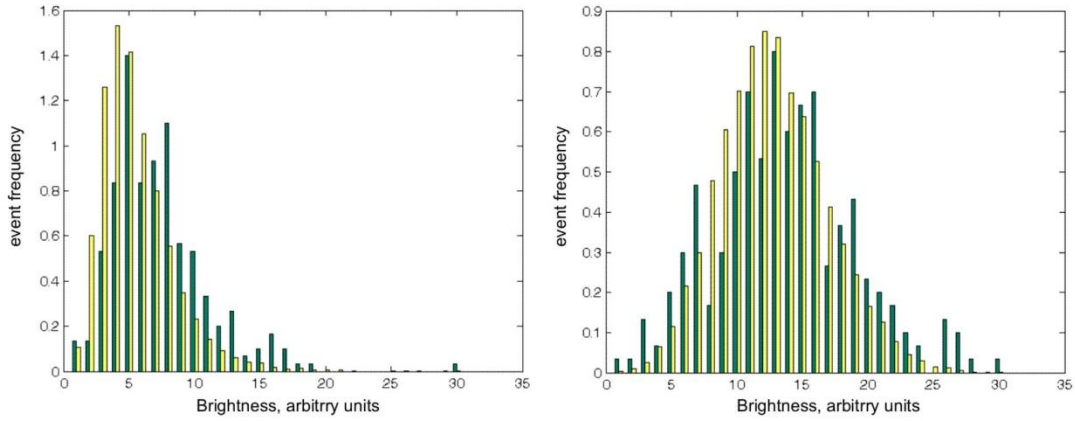


Figure 3: Two examples of histograms of the brightness distribution (green) and fitted data (yellow).

It should be noted that for the calculation of central moments we do not need even to store the primary images sequence. It is possible to keep in memory summarized images in first, second, third and fourth power which are the moments about origin. Central moments can be calculated later from the moments about origin by well known equations [7]

$$\mu_2 = \mu'_2 - \mu_1^2, \quad (1)$$

$$\mu_3 = \mu'_3 - 3\mu_1\mu'_2 + 2\mu_1^3, \quad (2)$$

$$\mu_4 = \mu'_4 - 4\mu_1\mu'_3 + 6\mu_1^2\mu'_2 - 3\mu_1^4, \quad (3)$$

Where  $\mu_i$  is  $i$ -th central moment and  $\mu'_i$  is  $i$ -th moment about the origin. Such an approach could be advantageous for online monitoring applications where evaluation would run in real time along with camera recording.

### 3 Comparison of two procedures of evaluation.

For the comparison we will call as ‘straight’ the method of straightforward data processing and as ‘fitted’ the procedure of data fitting by Pearson distribution and consequent fitted data processing. Both methods were run on the computer Pentium 2,8 MHz frequency with 1,5 Gbyte memory. A sequence of 500 images of fluctuating plasma jet with resolution 592x128 was treated.

In the Fig.4 the processor and memory load is shown for the running of the fitted method first and then the straight one. First peak of CPU load corresponds to reading of the images from hard drive. Significant increase of memory usage (cca 200 MByte) is apparent in the case of straight method while processing length is much longer (2 min and 20 second) for fitted method.



Figure 4: CPU and memory load for the fitted and straight method of data processing.

In Fig.5 there are results of the processing for the straight and fitted methods of processing. The results are similar. They show similar patterns of plasma flow fluctuations. The straight method bears a bigger influence of individual photographs, while the fitted method seems to better average the data. It is due to the deeper dependence of the fitted method on statistical parameters than on original data. The fitted method however shows bigger noise. The general quality of the maps allows both of them to be used in plasma flow structure analysis.

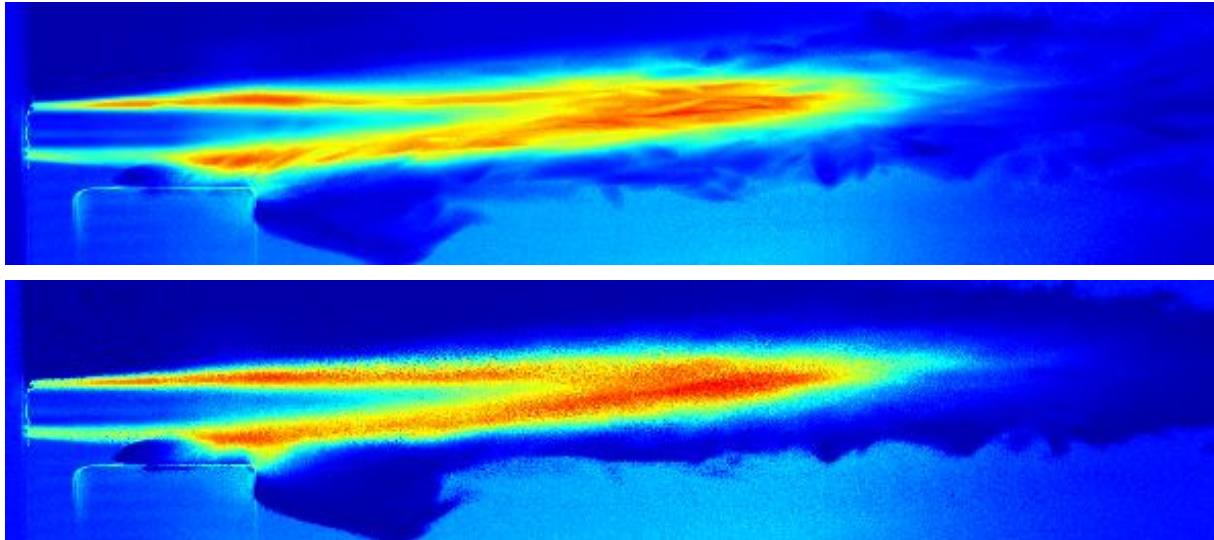


Figure 5: Map of brightness fluctuation in plasma jet photographic sequence. Results of straight processing (top) and fitted processing ways.

#### 4 Conclusion.

Two ways of data processing for the procedure of brightness fluctuation visualization are presented and compared. Matlab native functions were used for their realization. The straight method provides fast calculations but requires more memory while the fitted method saves memory but is more than 4 times slower. The results of both processing are comparable and can be used for the analysis and monitoring of fluctuating objects as plasma or flames. The methods complement each other and can be used depending on specific requirements of the processing.

#### References

- [1] Boulos M. I., "Visualization and Diagnostics of Thermal Plasma Flows", *Journal of Visualization*, 4: 19-28 (2001)
- [2] Duan Z., Heberlein J., "Arc instabilities in a plasma spray torch", *Journal of Thermal Spray Technology*, 11: 44-51 (2002)
- [3] Hernandez R., Ballester J., Flame imaging as a diagnostic tool for industrial combustion, *Combustion and Flame*, 155 (2008) 509-528.
- [4] Chimenti M., Di Natali C., Mariotti G., Paganini E., Pieri G., Salvetti O., An IR image processing approach for characterising combustion instability, *Infrared Physics & Technology*, 46 (2004) 41-47.
- [5] [http://en.wikipedia.org/wiki/Entropy\\_%28information\\_theory%29](http://en.wikipedia.org/wiki/Entropy_%28information_theory%29), 15.10.2011
- [6] O. Chumak, M. Hrabovský, Discharge fluctuations presentation by entropy maps, Book of Contributed Papers: 18th Symposium on Application of Plasma Processes, Slovak Republic, Vrátna, 15.-20.1.2011
- [7] <http://www.mathworks.com/help/toolbox/stats/pearsrnd.html>, 15.10.2011
- [8] [http://en.wikipedia.org/wiki/Central\\_moment](http://en.wikipedia.org/wiki/Central_moment), 15.10.2011

---

Mgr. Oleksiy Chumak, Ph.D.  
 Thermal Plasma Department, Institute of Plasma Physics, v.v.i.  
 Za Slovankou 3, 18200 Prague, Czech Republic  
 Tel.: (+420) 266 053 248  
 Email: chumak@ipp.cas.cz