VISUESC - FLOW VISUALIZATION AND IMAGE PROCESSING SOFTWARE FOR VELOCITY MEASUREMENT FIELDS BY “PIV” TECHNIQUE

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Abstract. The techniques of flow visualization have had a great development in 70’s with the firsts methods introduced in Laser applications, like LDV (Laser Doppler Velocimetry) and PIV (Particle Image Velocimetry). In these last ten years, due to digital camera CCD (Charge Couple Device) improvements, the development of frame grabbers and microcomputers with better processing performance and large memory, bi-dimensional and three-dimensional computational processing has been applied to dynamic of fluids and aerodynamic. This work presents the development of “VisuEsc” software, using C++ language and Borland 5.0 Compiler with OWL (Object Windows Library) for windows interface. The images are captured by a camera and digitized by an acquisition board installed in PC through PIV technique. The velocities measurements are done by image processing, evaluating the trajectory distance of particles previously spread in the fluid. This distance is measured computing the number of pixels between the initial and final trajectory point. The camera shutter set determines the time for this displacement. The methods to analyze these images are based on statistical properties, mathematical and logical functions. The images are loaded in a rectangular two dimensions matrix, which the lines and columns are the x and y coordinates. The values stored are the luminance level, which range from 0 to 255. With this data, the velocity vectors are calculated and plotted, making a flow “chart”.

Keywords: Flow Visualization, PIV, Image Processing, Signal Processing

1. INTRODUCTION

This work presents the implementation of "VisuEsc" software for velocities fields computing and visualization of fast flows (up to 10m/s) through PIV technique.

The particles spread in the fluid have an important role in the development of PIV systems and thus their choose is directly related to the performance of entire instrumentation process. The particle physical nature (polyethylene, pliolite, etc.), its density, shape, size, frequency (dynamic characteristics), light reflections properties and drag behavior in the fluid form the majors characteristics that have to be analyzed and developed for every particular application of PIV techniques (Adrian, 1991; Lourenço, 1996). Among these, in the high-speed and turbulent water flows, it is at least desirable that the particle has less than a 10μm diameter and density close to the water, avoiding drag in the fluid. The other characteristics can be compensated by image processing techniques.

1.1. Acquisition and image processing

The fluid flow images are captured by a CCD camera and have their contrast and bright level adjusted. Then, for the post processing algorithms, it is digitalized by an acquisition board connected to a PC (Personal Computer). The images sequence captured from the interest area of the fluid flow are stored in a standard BMP (bit mapped file) file.

Basically, to compute the velocity vectors, is must necessary evaluate the trajectory of each particle in the fluid, which is done by image processing techniques dedicated for the tasks (Shalkoff, 1989; Gonzales, 1993). The algorithms implemented for this comprise the matrix image generation, borders selection filters, particle centralization, erosion, pixel distance evaluation of two consecutives particle positions and, finally, the vector plot. Then, it is possible to calculate the 2D velocity vector for each particle and assemble the velocity field of the fluid area analyzed.

In the structured program, all the routines that form the algorithms used as well the manipulation of files and the presentation in Windows format was based on the libraries OWL (Object Windows Libraries) (Borland International, 1997).

1.2. Flow visualization Software "VisuEsc"

For treatment and processing of the captured images, it was developed a C^{++} program, named VisuEsc, based on Borland 5.0 compiler and using the OWL (Object Windows Libraries) libraries, that allows the generation of windows type screen format. This software is show in figure 1.

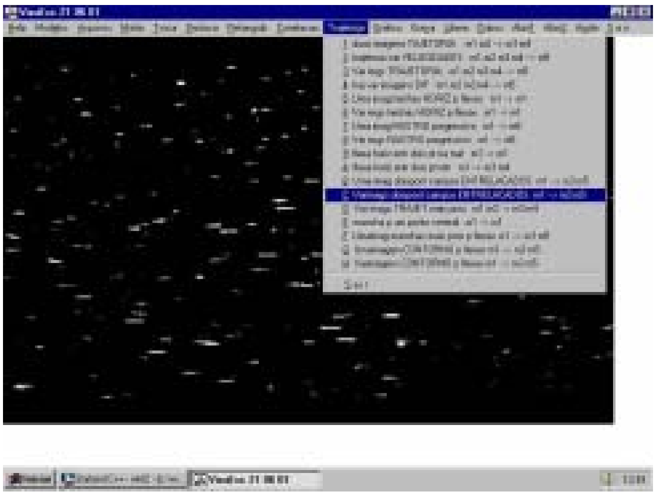

Figure 1. VisuEsc screen opened in Trajetória function

The program is constituted of functions and modules forms, gathered according to each task type. Classes are attributed to similar functions with variants for use in tests modes.

The techniques developed are structured in the formation of matrix image, resulting in an original derived BMP file. Basics routines execute the manipulation and transformation of these matrix images, making this proper for the future flow visualizations. In figure 1, the trajectory item set the field interlaced operation mode, described below (item 2.5). Tests were developed to validate each function, executing this step by step through all developed logical functions.

2. THE IMAGE FUNCTIONS

The format of the BMP files, its reading and recording, the headers and image “buffers”, constitute the functions formation of the main image. The images are loaded in a two dimensions rectangular matrixes, whose domain is formed by the number of lines and columns that set the image coordinates “x,y”, according to the equation (1):

$$f(x,y,l) = F = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & \vdots \\ \vdots & \cdots & \cdots & \vdots \\ f_{m1} & \cdots & \cdots & f_{mn} \end{bmatrix} \qquad (1)$$

The luminance “l” of the image, contained in each position of the matrix and indexed by the lines and columns, form the space surface (that is shown in Figure 2). In his way, it is allowed process and transform the images by any mathematical operator.

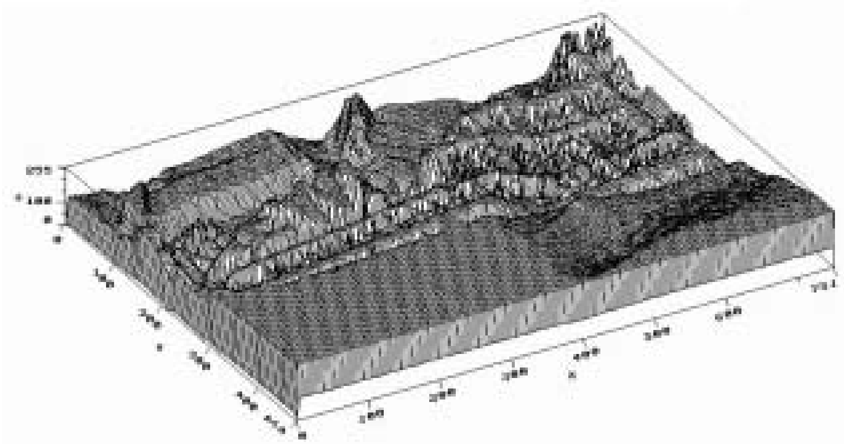

Figure 2. Matrix representation (x,y,l).

2.1. Function manipulation and image transformation

Structured with five work “buffers”, the program allows the manipulation by overlap, contrast and bright adjustment (Equations 2 and 3 respectively), levels discrimination (according a mathematical law like step function and its 1st and 2nd derived), and transformations as border filters, particle centralization by peak detection, erosion, correlation and autocorrelation.

$$E = wF \tag{2}$$

$$E = k \pm F \tag{3}$$

2.2. Scale functions and calibration

This function generates calibrated grids in m/s to adjust the scale factor for the speed vector calculation. It allows the generation of modules and lists the velocity vectors and its coordinates location.

2.3. VisuEsc Description

The operations of the VisuEsc applicative, disposed in the contends top box of the main screen (see Figure 3), allow the manipulation and the processing of the different BMP files, for the final visualizations of the speed fields.

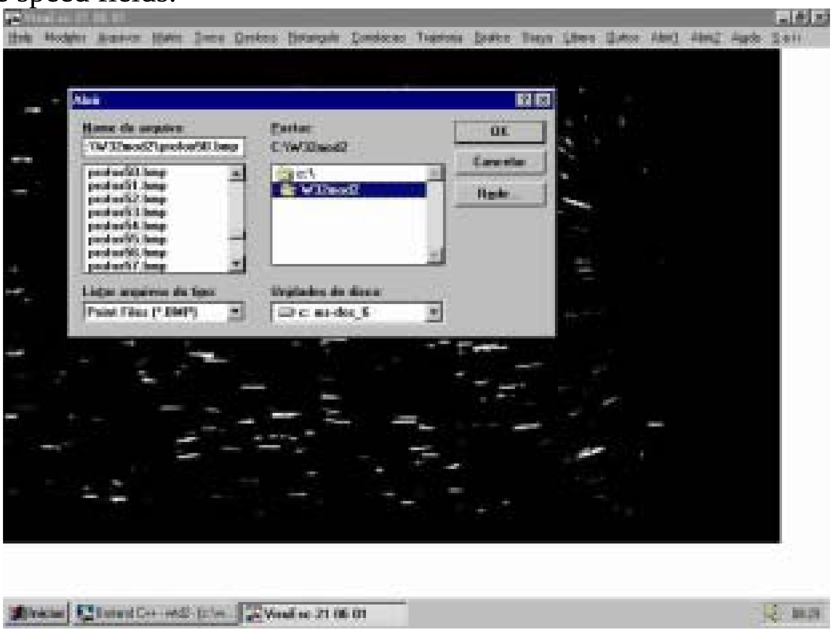

Figure 3. VisuEsc Windows interface.

For each operation, a window is open to execute the selected functions. The figure 3 shows the “load Files” operation, which open and save files in the five buffers (M_1 to M_5). In this screen, the sequence of files “PROFOX50” can be selected for processing. The image showed in the background is generated in this file.

The “Matrix” operation allows the manipulation of images placed in the buffers M_1 and M_2. It can be a multiplication by constants (contrast control) or a sum/subtraction by constants, to control the brightness.

“Move” allow the transfers of an image from a buffer to another, and the consequent overlap of two buffers.

“Rectangle” allows selecting an area of the image (used in the operations matrix/window) determined by the parameters.

“Correlation” allows the correlation among buffers, of the whole screen, as well as the one of a selected area in the operation “Rectangle”. It can execute the correlation and autocorrelation.

“Track” allows the processing of the functions that will generate the visualizations of the speed fields.

“Graphics” shows the content of the five used buffers and allow that it would be saved and later exported.

“Others” generate the calibration scales in m/s of the visualizations, as well as the lines that characterize the limits of the acrylic tube and others functions not yet implemented.

2.4. Flow chart operations

The follow diagrams describe the entire software with its routines and subroutines. It is show in figure 4 and 5.

2.4.1. Trace of the particles operation

A BMP file, named in the form by “PROGMO50”[1], is the original image selected in the first operation (see figure 4). In the sequence, the file is transformed in a m x n matrix, which is saved in the buffer M_1. Variables such as the number of files of the selected type, discrimination level and scale in pixels for markers are inputed by keyboard.

The next block transforms the image in binary form starting from the selected level. The filling function stores in the M_5 buffer the transformed image of the velocity vectors.

In this point, all operations are repeated for the images captured sequentially until the number “N” is reached, which signs that the entire velocity field is computed (10 images for each field).

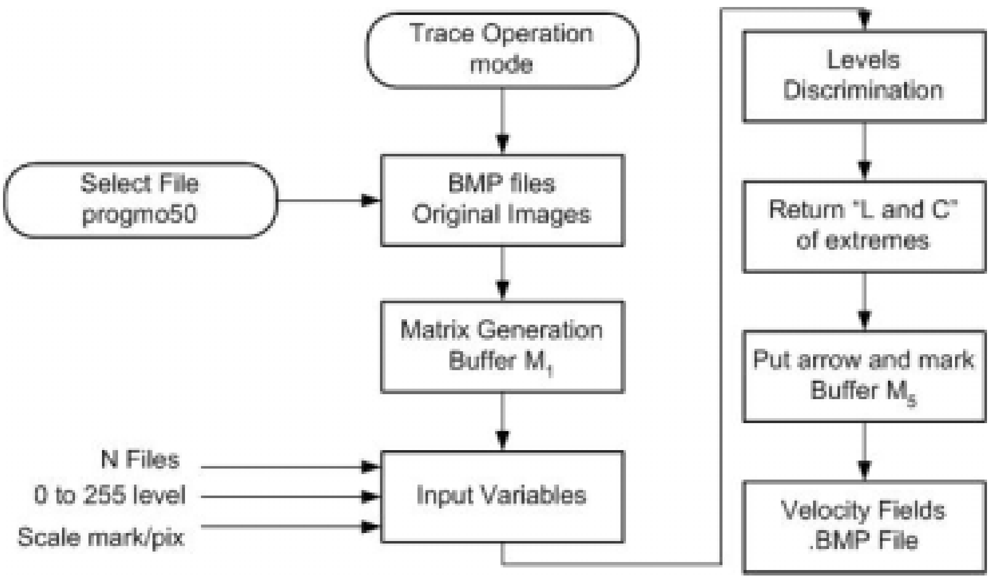

Figure 4. Flow chart of trace operation mode.

In order to test the algorithms, the routine can be executed using a single file with low vectors density. Making an overlap of the original image (buffer M_1) and the transformed image (buffer M_5), the instantaneous verification of the program can be done. Finally, this transformed image file is generated to export.

2.4.2. Interlaced fields operation

In the interlaced fields mode (Figure 5), from the first blocks (files load and matrix generation) until the input variables function, the operation is similar of the particles trace described previously. The file “ENTAMO10”, interlaced mode and shutter 1/1000s are selected. An additional variable is introduced, to limit the number of pixels (“n” pixels) of the search. In the flow chart, this operation discerns the pairs of particles. The discriminator level, differently of the previous operation, executes a background discrimination, in order to eliminate the image noise. The vertical borders

[1] File constitution “PROGMO50” [progressive, inward, (5) shutter 1/500, (0) number].

detector removes the image raster, just leaving two individual points. The following function determines the respective particles centers for precise positioning of the velocity vectors. In the search of the pairs of particles, it is done its separation. So that, the vectors arrows are positioned correctly when appears individual particles close to the pairs.

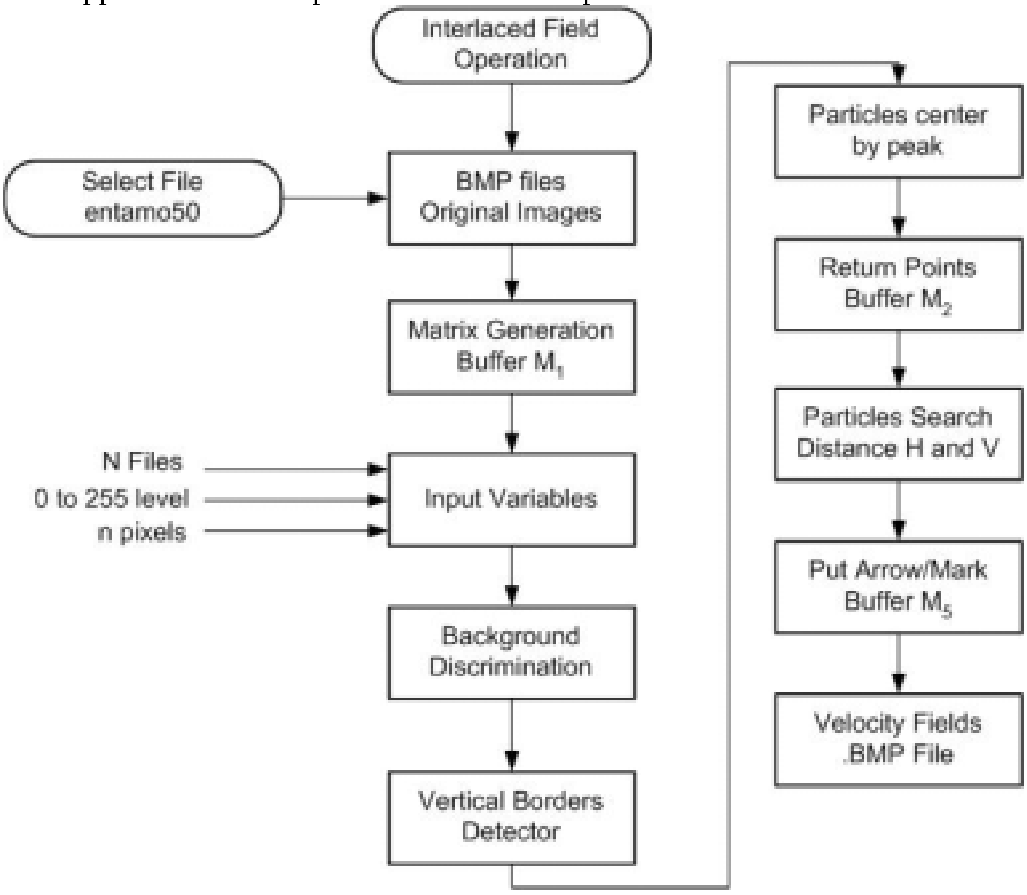

Figure 5. Flow chart interlaced fields operation.

Finished the arrows placement for the selected file, the operation will be repeated for a "N" number files, resulting the final visualization of the velocity fields. In this operation, an additional M_2 buffer is used, which retain the image of the individual points, characterizing for each particle an individual pixel and eliminating the circular geometry remaining that forms the particle.

3. AREAS FILLING

In the trace particles process, the velocity vector is defined by the luminous trace left by the particles (see figure 6a) that is characterized by a three pixels of thickness line. The logical function developed implement a thick line centralized inside the trace described above (the velocity vector). Sweeping the image, the most extremely left line pixel is located. Starting from there, it is marked until de most extremely right pixel is reached. Then, all the pixels of the identified trace are erased (filled with zeros), just remaining two points, which will be interlinked with an arrow (figure 6b).

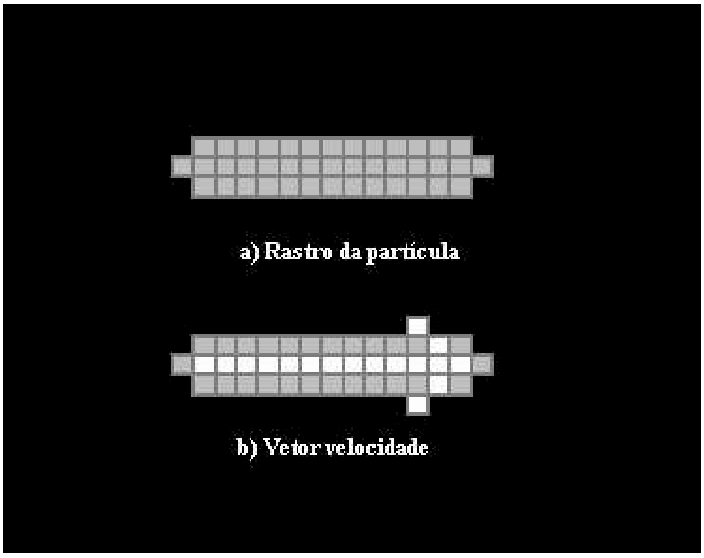

Figure 6. Filling function areas: a) Particles Trace, b) velocity vector.

In the original image, an extreme point in the left and another in the right characterize the trace left by the particle displacement. Due to the spherical particles nature, its projection is rounded in the corners. The point's ends are the central points of the trace of three pixels of thickness. Thus, the fine vector of a line of a pixel of thickness, centralized inside of the trace, is similar to the erosion process used in treatment of images in the area of morphology (Schalkoff, 1989), and can be realized by this logical function, much simpler to being implemented.

The complete field can be observed in Figure 7. It is originated in a 2,5 cm input hole plate. The field was plotted in a 2 m/s scale and calibrated by the grid superposed in the image.

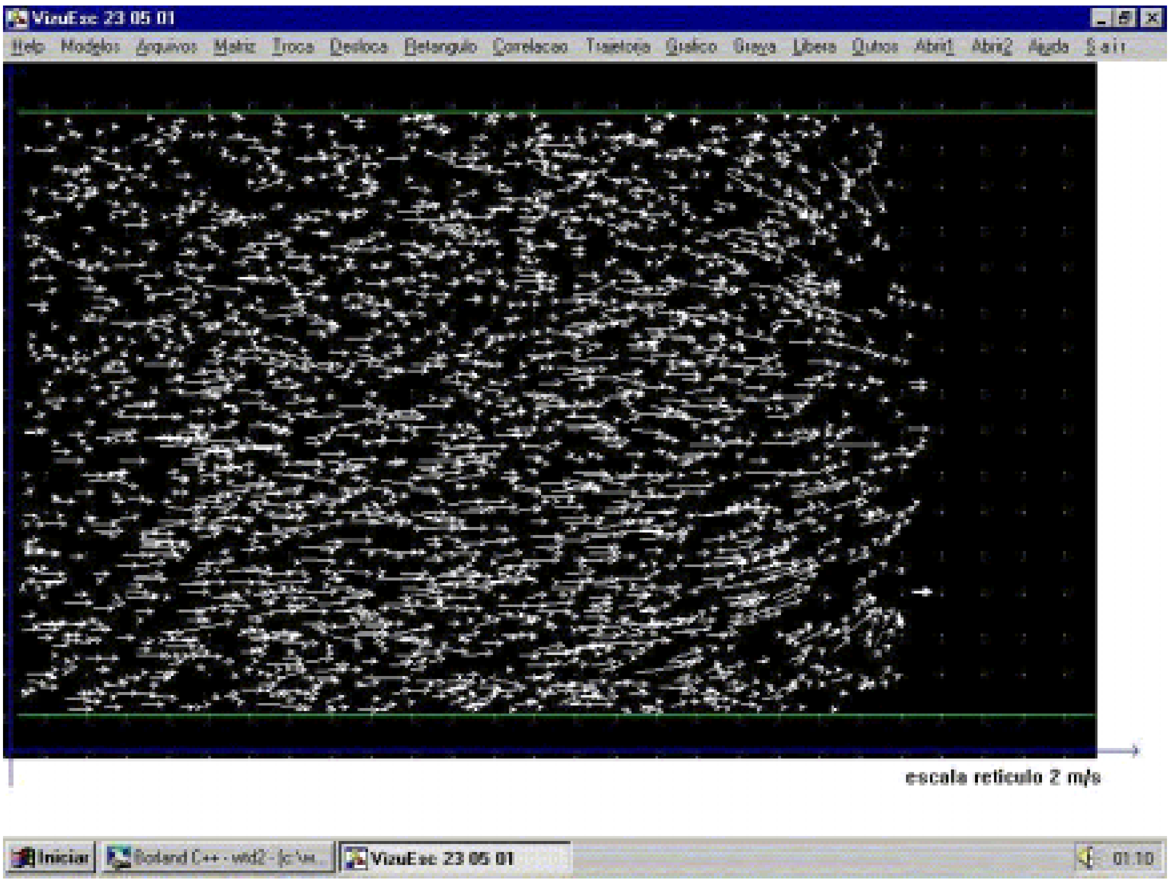

Figure 7. Flow visualization near a plate hole in an acrylic tube.

4. CONCLUSIONS

This paper shown the development of a software able to process ten images in the interlaced fields technique (worst condition), taking less than 20 seconds to calculate and draw the velocity flow field of the interesting fluid area. Also, it is shows the advantage of implementing logical functions instead of applying more complex mathematics algorithms. This tool uses functions that allow the analysis and process of any image captured by the cameras. Due to its modular structure, correlation algorithms and geometric distortion corrections (in corners) can be easily implemented in VisuEsc.

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