DEVELOPMENT OF A REAL-TIME FOCUS ESTIMATON SOFTWARE TO BE APPLIED IN TWO-PHASE FLOW IMAGING USING INTELIGENT PROCESSING

Marcones C.B. da Silva[1], Sandro M.C. Schott[2], Roberto N. de Mesquita[3]

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP, Brazil
[1]marcones@usp.br
[2]sandro.schott@usp.br
[3]rnavarro@ipen.br

ABSTRACT

Image processing has been an increasing research area in the last decades, especially due to crescent technological growth allied with lowering production costs. Many scientific applications have searched for establishment of quality norms associated with possible information obtainment from images. A common need from different applications has been the standardization of focus quality metric. The development of new methods for measuring the focus adjustment in order to obtain image quality metric analysis has enabled more reliable and precise data in many different industry and science sectors. Some examples are industrial equipment parts inspection using computational vision to defects classification. This work presents the initial steps to develop a methodology to estimate focus in real time in two-phase flow experiments inside tube with cylindrical geometry. This methodology is initially based on a software module using artificial intelligence methods to estimate image focus. This module is developed in LabVIEW platform using Fuzzy Logic inference base in different traditional digital focus metrics and integrated with digital cameras to increment precision on focus adjustment during two-phase flow experiments. This method will be calibrated to be used on void fraction estimation through image analysis in the natural circulation loop located at the Nuclear Engineering Center (CEN) do Instituto de Pesquisas Energéticas e Nucleares (IPEN). A set of the initial developed software modules will be presented with their respective functionalities, initial results and experimental focus estimated errors.

Keywords: image processing, focus adjustment, image quality, Fuzzy Logic, focus metric, image acquisition, two-phase flow.

1. INTRODUCTION

A scientific image can be described as a partial or complete representation of a "scene" from which information is to be extracted. This information can surpass the human perception capacity. Information can be the dimensions of some objects, as length, height, width, and can be associated with other properties as texture, and rugosity which usually enable estimation of associated measurement errors [15]. The digital and systematic analysis of scientific images is a growing study area which encompass areas such as medical physics, material analysis, microscopy [2], astronomy, digitalization systems using satellites, and many others.

An important application of image analysis has been developed at the *Centro de Engenharia Nuclear* from IPEN. Experimental images of two-phase flow phenomena associated with natural circulation have been analyzed and studied using support of artificial intelligence techniques [3], [9], [14]. The natural circulation is being used as a passive system of heat removal of new developing nuclear reactor designs [21]. Similar efforts are done in studies using reduced scale of tubes with multiphase flow phenomena in petroleum extraction industry [19].

Some thermohydraulic studies of multiphase flow has been using digital visualization for specific problems related to optical cylindrical effects during image acquisition [14]. Image distortion due to optical refraction implies also in diminishing focus precision which may cause difficulties on parameters estimation through acquired images.

A usual difficulty in scientific image analysis is to evaluate the focus level associated with acquisition of image or part of it (Region of Interest – ROI). Human vision is able to perceive an image with many details and out-of-focus can be rapidly identified and recognized. Images captured through electronic devices usually have much more limited results. The captured digital image may present many implicitly regions out-of-focus [1].

The measure of focus variation can be of importance to estimate scientific parameters, especially in situations where the depth information is of relevance. However, the depth of field (DOF) of image acquisition is determined by acquisition distance, optical lenses aperture, and others.

The recent development of digital image acquisition apparatus has implied in the need for new analysis' methodologies which should allow evaluation and quantification of image features of these scientific images.

This work presents the development of a methodology based on an image acquisition and processing software which is based on a Fuzzy system. This inference system was developed using the software LabVIEW™ and MATLAB™. The algorithm was developed to evaluate in real time the quality of focus from a ROI which is selected using the control interface which is connected to the cameras being using in a experiment. The possibility and necessity of having this control of focus online for scientific applications is cited by Huang and Jing [5]. The proposed methodology includes as first step, the selection of a ROI and then evaluate the focus level from that region. This evaluation is realized by an Fuzzy Inference System which uses as input two classical focus metrics. The method also enable a possible comparison of different methods depending on which acquisition condition surrounds that specific ROI and increasing the robustness of its results. It is common in some experiments (especially dynamic flows) that the object of interest should vary its position in the flow or its scene. This feature rises the need to estimate online the condition in which the images are being done. The experiments done to validate the method were initially realized using a geometry and conditions which should be applied at future two-phase flow experiments in the Natural Circulation Circuit of the *Centro de Engenharia Nuclear do Instituto de Pesquisas*

Energéticas e Nucleares (IPEN-CNEN/Sp). Most of these experiments using images have been published in recent years [3], [5], [9], [10], [14], [21].

The paper has the following order: Section 2 presents the Methodology, the results and calibration from experiments are discussed on Section 3, and the conclusions on Section 4.

2. METHODOLOGY

In this section the methodology and the experimental planning used in this work will be described. Besides the description of experimental equipment, a description of the main analysis methods will be provided.

2.1. Image acquisition system

Image acquisition process involves many different devices in order to capture a real image and transform it into a digital image [9]. The experiment was conceived with the objective to calibrate the focus of two cameras under the same optical and luminance conditions. These results should enable the consequent adjustment of the developed software tool to infer a focus quality number.

Two similar cameras were positioned with 90º angle between them, to acquire images from an object positioned above a plastic cylinder as shown on Figure 1. This geometrical disposition will enable future simulation of two-phase flow acquisition in the Natural Circulation Circuit of the Nuclear Engineering Center of the Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN – Sp) [3]. This experimental loop is consisted of cylindrical glass tubes. The experimental setup was planned in order to enable the variation of acquisition distance and 'region of interest' (ROIs). The object to be imaged was a set of 5 pins which were disposed on a 45º angle line with respect to each camera. This setup was used to compare the online measurements obtained from the algorithm using different focus metrics.

Each camera was fixed in a metal basis (adjustable support) constructed in order to control the variation of acquisition distance and angle. Figure 1 shows the disposition of cameras used for this experiment.
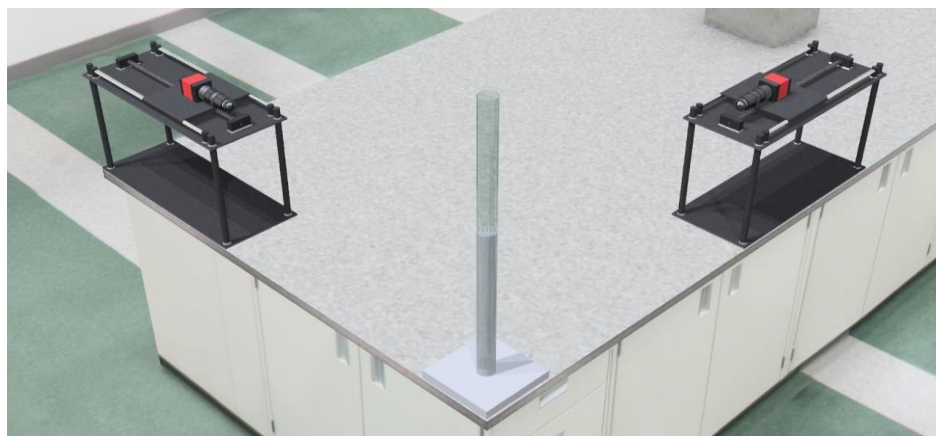
Figure 1- Cameras adjustable support.

The image acquisition was performed controlling the following parameters:

- Focal distance;
- Camera aperture;
- Depth-of-field;
- Illumination.

These parameters were chosen as the more important to assure similar conditions of image capture with similar conditions. These acquisition conditions will be described throughout this work.

2.1.1. Oscar F-810 cameras

The methodology developed in this work is based on images acquired using two high resolution cameras from Allied Vision [13]. These cameras' model is the F-810C™. They have asynchronous triggers and resolution on the 3 to 8 megapixels range. The image capture device is a SONY CCD ICX-456AQ, where the image frame size is 3272 x 2468 pixels. The power requirement is a 8V to 36 VDC through IEEE 1394 cable or a HIROSE 12 pins cable. A detailed image is shown on Figure 2.

Figure 2- Oscar F-810c™ [12] camera

2.1.2   KOWA™ LMZ69M lenses

The lenses used in each camera were two Macro Zoom lenses from Kowa™ Company Limited. For this work the evaluation of objective focus measurements is dependent of some basic geometrical parameters related to image formation. Figure 3 shows the basic optics of used lenses.
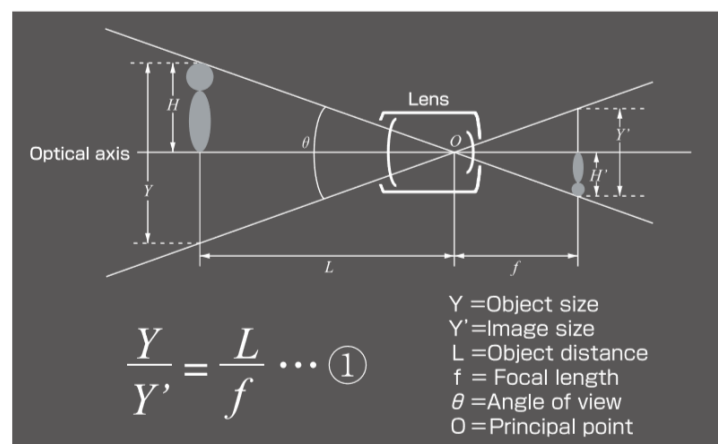

$$\frac{Y}{Y'} = \frac{L}{f} \cdots \text{①}$$

Y = Object size
Y' = Image size
L = Object distance
f = Focal length
θ = Angle of view
O = Principal point

Figure 3- Basic image geometric optical formation using optical lenses [8]

The main elements of Figure 3 can be described as:

Y- object size indicates the possible object size that can be captured by the camera sensor;

Y'- image size is directly related to the size of the camera image sensor device;

L- is the distance from the lenses to the object;

f – is the distance from optical focus to the sensor;

Ө- the field of view estimates the angle used to image capture. The larger the view angle, smaller will be the focal distance.

Figure 4- Kowa™ LMZ69M lenses model [8]

The image formation at the camera sensor is dependent on parameters as aperture and focal distance that can be adjusted and controlled varying the inherent distance positions of internal lenses that constitute LMZ69M. This control is obtained by adjustable rings of the lenses set.

2.2 LabVIEW™ Control and Focus evaluation module

LabVIEW™ software platform has a set of modules to acquire and process images. The *VDM* (*Vision Development Module*) is the development module which contains functions which are related to image processing (filtering, segmentation, equalization and thresholding). This module was the basis for the development of the Focus Measurement Interface.

Image acquisition was done using *NI-IMAQdx* submodule. This submodule is an Application of Programming Interface (API) which can be used to control simultaneous image acquisitions from different cameras [20].

The programming is mainly done by graphical icons interlinked by movable lines which determine data flow and ordering [16].

Figure 5 shows the Virtual Instruments (VIs): "*IMAQdx configure grab*" and "*IMAQdx Grab*" [16], applied to instantaneous image acquisition.
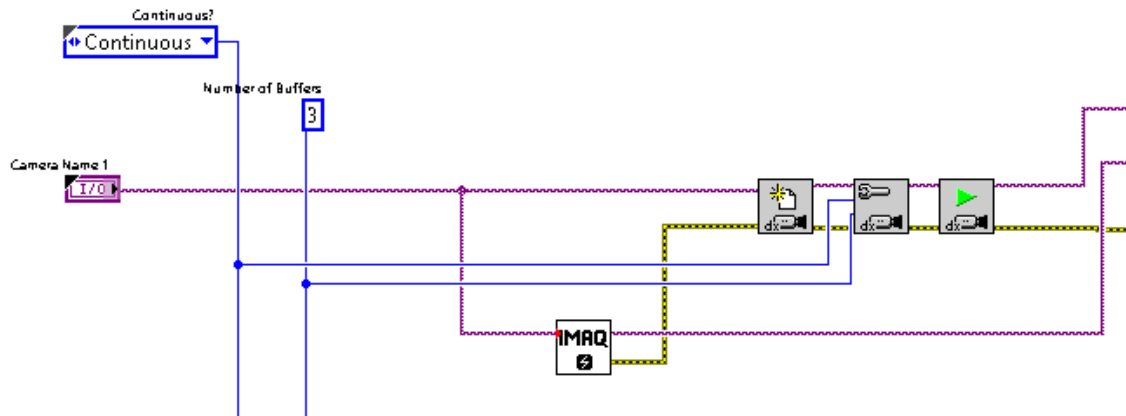
Figure 5 – Block diagram using VIs from IMAQdx

Using these VIs is possible to have control over acquisition. The images are sent to a software internal buffer to enable image visualization through a graphical control interface.

2.2.1 Focus evaluation algorithms

To obtain the focus evaluation in real time a set of focus measures were used based on published algorithms [1] [5], [6], [7], [17], [18]. These algorithms are implementations of different focus metrics. The application of these algorithms to image matrixes representing 'Regions of Interest' (ROIs) results in focus measures. The ROI are chosen selected areas from acquired images.

Most of these focus measures are done using matrix transforms on temporal and frequency domains. Each measure has a different nondimensional number pertaining to a different range as result. Usually temporal domain measures have smaller computational cost and therefore are faster processed.

There were 28 different algorithms to obtain focus measures according to Cardoso [2]. Each metric has specific execution cost and is better fit to different image characteristics. The fuzzy inference system proposed in this work enables the comparison and integration of two different metrics. The tests were done using two metrics which present fast processing described in "*Tenegrad*" (TN) [7] and "*Energy of gradient*" (GRAE) [5].

2.2.2.1 Sobel variation – *Tenegrad (TN)*

One the most traditional metric to estimate focus is known as "Gradient Magnitude Maximization", which is also called as Tenegrad (TN)[1]. The metric is based on the observable variation of gray intensity level (I(x,y)) in the image region which is defined as the border of region of interest [7]. The gradient, $\nabla I(x,y)$, is estimated in each image point and the values larger than a predefined threshold level are summed as shown in Eq. 1 and 2.

$$\nabla I(x, y) = \sqrt{Ix^2 + Iy^2} \tag{1}$$

The gradient magnitude is evaluated using Eq.2:

$$(x, y) = \sqrt{|ix * I(x,y)|^2 + |iy * I(x,y)|^2} \qquad (2)$$

Equation 2 is evaluated based on applying 3x3 masks over the image. This operation works as filters detecting fine details or large variations of gray level. The masks are applied over the image through a scanning process line by the line, and this operation is known as convolution. The applied masks to obtain *ix* and *iy* gradients are respectively:

$ix =$
(3)

-1	-2	-1
0	0	0
1	2	1

-1	-2	-1
0	0	0
1	2	1

$iy =$

2.2.2.2 Gradient Energy *(GRAE)*

This focus metric is based on local differential operator, usually applied to find image borders [5]. This measure is usually described according to Eq. 4.

$$GRAE = \sum x \sum y \left(f_x^2 + f_y^2 \right), \qquad (4)$$

Where:

$$f_x = f(x + 1, y) - f(x, y) \qquad (5)$$

and,

$$f_y = f(x, y + 1) - f(x, y) \qquad (6)$$

GRAE metric is similar to TN, however uses the gradient approximation using gray level intensity differences between neighbor pixels along a scan line instead of using Sobel operators.

2.2.2 LabVIEW™ implementation

The implementation of the fuzzy inference was done using the integration of graphical programming of *LabVIEW* ™versão 2017 with Matlab script algorithms. Focus measures were implemented in Matlab based on implementations found in literature [17], [18].

The graphical units in LabVIEW are used to control image acquisition and posterior image analysis (Figure 6).
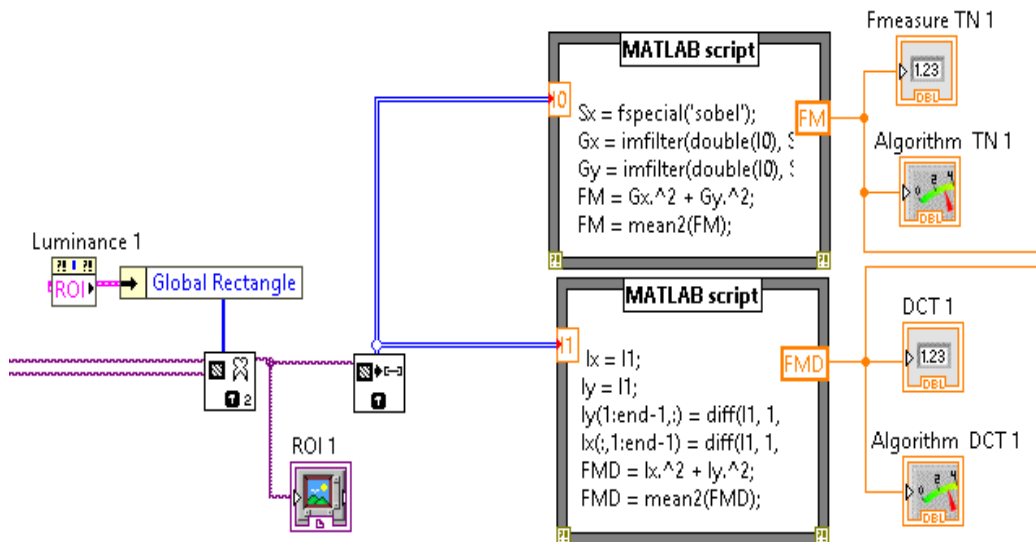
Figure 6 – TN algorithm implemented in LabVIEW using MATLAB script.

2.2.3 Fuzzy inference in LabVIEW™

The developed fuzzy inference system uses interactive resources of LabVIEW graphical programming. Figure 7 shows the diagram of programming blocks called VIs. These VIs are responsible for the analysis data flow in order to obtain the final inference results. The inference and other data flow are exhibited in a dashboard which will be presented on section 2.3.
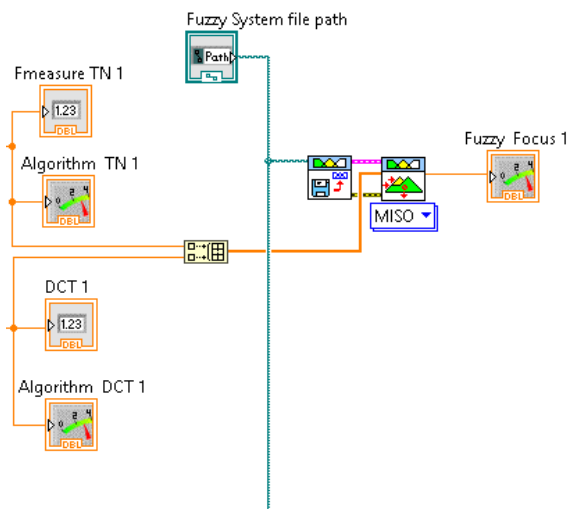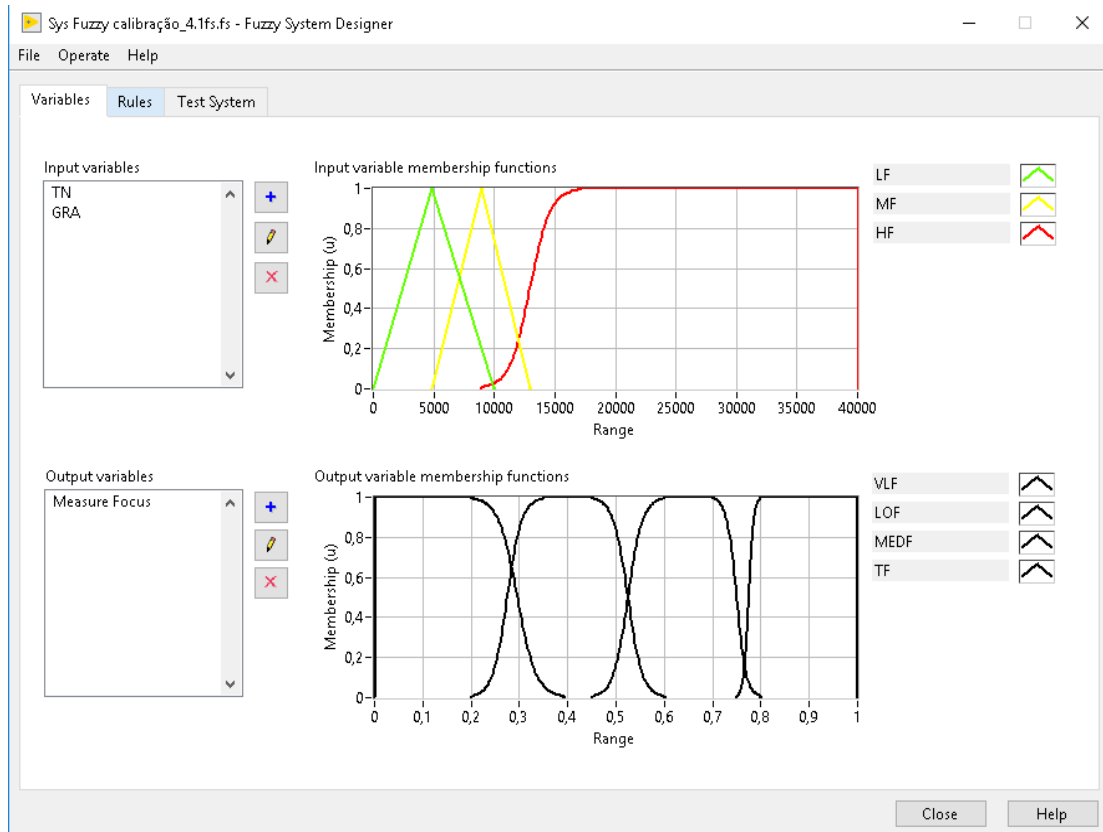

**Figure 7– LabVIEW blocks (Vis) for focus fuzzy inference implementation.**

Figure 8– Input and output variables defined on System Fuzzy Designer graphical interface.

The *Fuzzy Logic System* (FLS) is an intelligent system that allows logic inference based on linguistic and numerical variables. [12]. This system is based on Fuzzy Logic and is usually composed of three basic phases: *fuzzification*, inference machine and *defuzzification*. These phases were implemented and calibrated using the LabVIEW control tool *System Fuzzy Designer* (Figure 8).

2.3 Focus evaluation dashboard

The developed dashboard can be visualized on Figure 9 showing its main available resources. This panel presents the main information related to the focus measurements using the algorithms and inferred by fuzzy system and shows the results interactively. Most of the panel is constructed based on LabVIEW VIs.
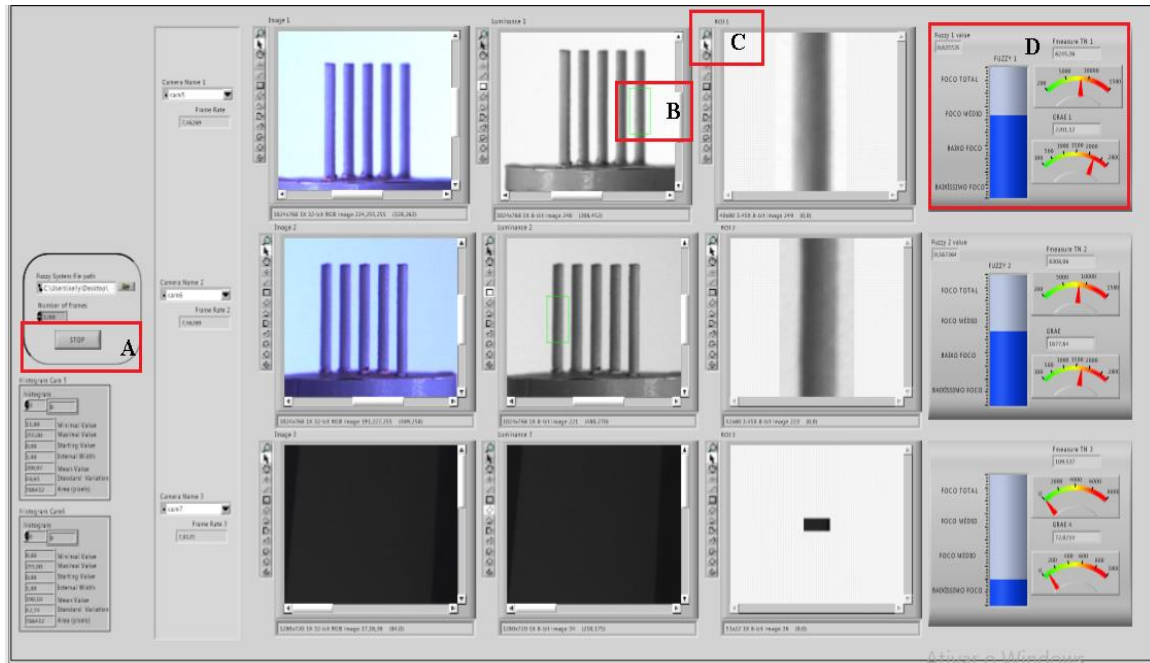
Figure 9- Focus measurement inference dashboard.

The main resources of fuzzy inference system dashboard (Figure 9) are described below:

A. **Acquisition stop (STOP):** This button allows the acquisition interruption. The obtained data will be available in each dashboard field enabling further evaluation;
B. **Region of interest selection (ROI):** The selection of ROI is very important to implement image analysis. This function allows the precise definition of which area is under evaluation. A appropriate selection may optimize inference and diminish computing processing time leading to more robust results;
C. **ROI display:** These screens display the ROIs visualization. Through this information (and inference results) the user can make needed adjustments to acquisition parameters such as focus distance determined by objective lenses disposition.;
D. **Measured focus level indicator:** These indicators are important to visualize instantaneous results from focus inference. The focus level is indicated by the blue bars. This information enables the manual adjustment of focus distance by the acquisition cameras used.


3. RESULTS

The proposed methodology evaluation was done with experiments using image acquisition of 5 cylindrical pins disposed on a circular basis (P1, P2, P3, P4, P5). These pins are separated by a 5 mm distance (Figure 10). This circular base is positioned above a cylindrical base with 37 mm diameter. These dimensions are similar to usual experimental setup used to acquire images from two-phase flow experiments at Ipen [13].
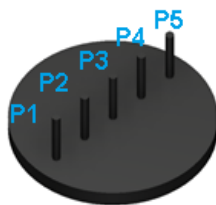
Figure 10- Cylindrical pins disposed on a circular basis separated by 5 mm distance.

Figure 11 describes the acquisition distances used in the focus calibration experiment. These distances are evaluated to each of the five pines of the object imaged in order to obtain experimental focus measures.
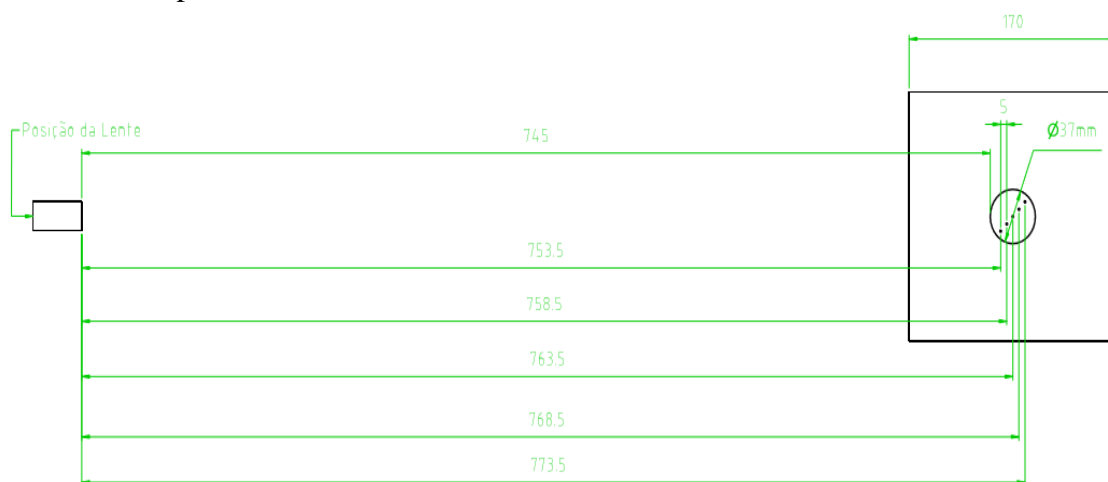

Figure 11- Focus calibration acquisition distances.

The focus acquisition experiment setup is represented in Figure 12. This system was described on section 2.


Figure 12-Focus calibration experimental setup.

Calibration experiment was adjusted using two LED lamps of 6000K color temperature. These lamps were positioned beside each camera. The lenses aperture was established based on the histogram mean value obtained from captured images. This procedure leaded to aperture varying from f/2 to f/2.8. Some typical images captured are shown on Figure 13. These images were taken with measured illumination in the range of 330 to 385 lux.

(a)	**(b)**
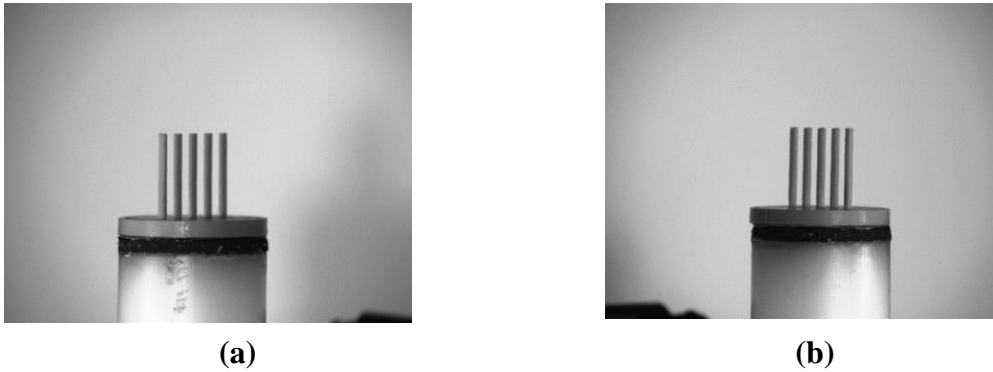
Figure 13- Captured images from right positioned camera (CAM5) (a) and left positioned camera (CAM6) (b).

The corresponding histogram data from each image are presented on Figure 14.
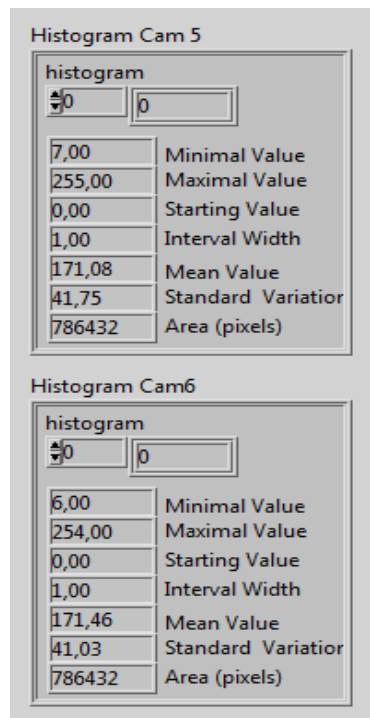
**Figure 14- Histogram data from images presented on Figure 13.**

The focal distance was defined in 50mm, the cylindrical support base had a 37mm diameter. The minimum acquisition distance was 280,3 mm. The focal plane was established using the developed graphical user interface following the steps bellow:

- The nearer pin (P1) was selected with an ROI with 40x80 pixels, as shown on Figure 15;
- The lenses were adjusted to maximize the resulting focus inferred from the fuzzy system (Figure 15(b)) using the two metrics: *TN1* (*GRAE1*) *and TN2* (*GRAE2*) as input.

(a)   **(b)**
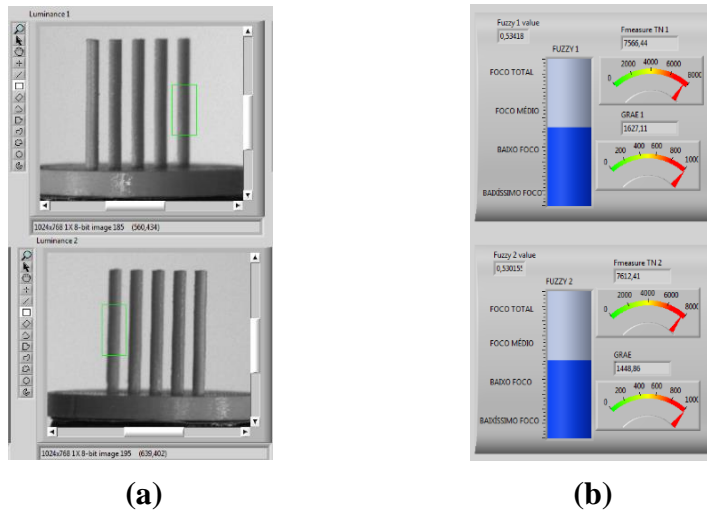
Figure 15- Selected ROIs (a); Focus level indicators from used input measures.

In this paper we present two experimental focus measures done in order to evaluate and adjust fuzzy parameters. The experiment is proposed in order to verify the agreement of the results for both symmetrical cameras which are under approximately the same optical conditions. The influence of variables as the ROI size, depth of field (DOF) and illumination intensity should be part of observations.. The obtained results for two experiments are shown on figures 16 and 17.
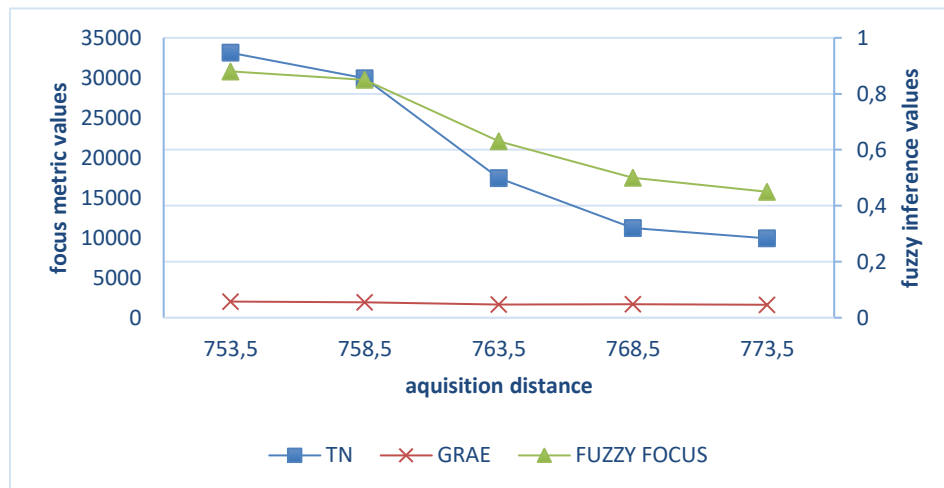
Figure 16- Fuzzy inference for TN and GRAE as input on experiment 1.

Focus values inferred for different acquisition distances for ROIs selected on pins P1 to P5. TN metric has shown to have more sensitivity to variations on acquisition distance. GRAE presented less sensitivity. Pin P1, which was imaged using a 753.5 mm distance, presented an estimated TN focus value of 33126. P5, positioned at 773.5 mm, this value was 9922,19. The GRAE values were respectively 2022.9 and 1621.5.
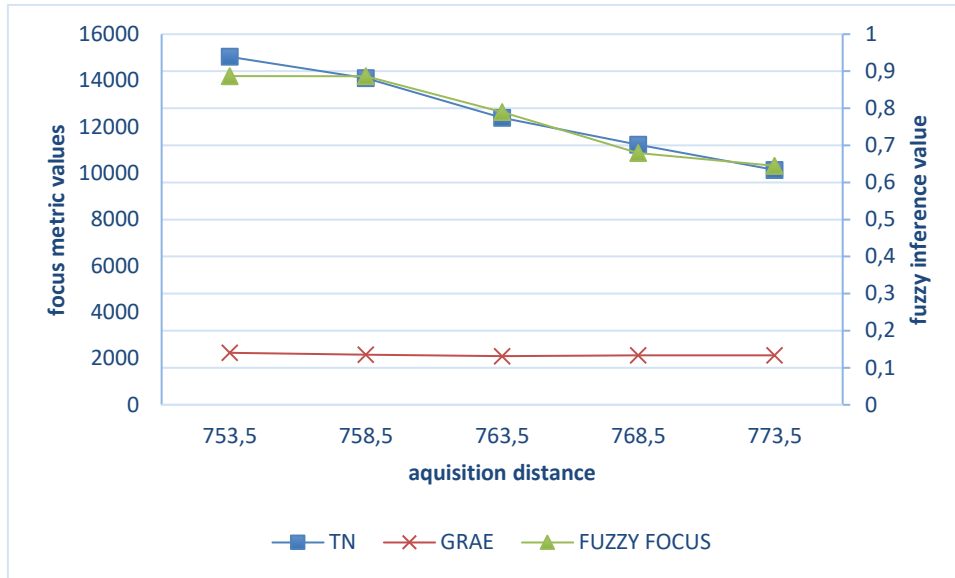
Figure 17- Fuzzy inference for TN and GRAE as input on experiment 2.

The focus measurements for different acquisition distances have presented similar results both in experiments 1 and 2. However the variations are much larger in experiment 2 due to illumination. Experiment 1 was done under 385 lux and experiment 2 under 330 lux. These differences due to luminosity variations reinforce the need to use an inference system using more than one metric. To the same experiment image, different ROIs may present different light incidence giving variable results.

The image acquisition was done maximizing focus at the nearer pins. The used cameras and lenses were adjusted to have small Depth of Field (DOF). The estimated DOF for this experiment was 10 mm.

The software has shown good efficiency to evaluate the focus values for both cameras under similar optical conditions and for different selected ROIs. The maximum focus values obtained were correspondent to 85% to 88% focus inferred quality value. For the selected ROIs for pins with larger acquisition distances, the inferred focus values correspond to 45% to 68% focus values.

4. CONCLUSIONS

This work has described the initial development steps of a system to infer the level of focus from image ROIs of scientific experiments. The ROIs' selection, image acquisition can be controlled by a graphic interface which enables refinement on image acquisition during experiments. The inference system uses Fuzzy Logic to establish grades of focus quality and is based on traditional focus metrics.

The experiments have shown that:
- The methodology of focus evaluation using the developed software increases reliability of acquisition parameters such as: lenses aperture, focal distance, acquisition distance, luminosity and depth of field.
- The control of ROIs' focus is an important tool for quantification and estimation of acquired image properties, such as bubble diameter in two-phase flow.
- The use of fuzzy inference enables a flexible tool that can be dynamically used to estimate different regions of image being acquired.

The results showed promising results both of inference system and image acquisition control of the cameras. The proposed methodology has shown to be relevant in estimating uncertainties related to image focus quality. This system should allow the full development of a valuable tool to the study of images of two-phase flow experiments on natural circulation. The same system could be used for other important scientific applications.

ACKNOWLEDGMENTS

REFERENCES

1. ANAICE Rafael; Facon, Jacques . *Avaliação de Nitidez em Imagens por Aprendizagem*. In: 23rd SIBGRAPI – Conference on Graphics, Patterns and Images, 2010, Gramado. 23rd SIBGRAPI – Conference on Graphics, Patterns and Images, 2010. v. 1. p. 1-4.
2. CARDOSO, Gabriel Schade. (2016). *Avalição e Aplicação de Algoritmos de Medidas de Foco em Imagens Obtidas por uma Plataforma de Holografia Digital Inline*. Dissertação de Mestrado, Computação Aplicada- UNIVALI, Itajaí/SC.
3. De Mesquita, R.N., Masotti, P.H.F., Penha, R.M.L., Andrade, D. a., Sabundjian, G., Torres, W.M., Macedo, L. a.: Classification of natural circulation two-phase flow patterns using fuzzy inference on image analysis. Nucl. Eng. Des. 250, 592–599 (2012).
4. GONZALEZ, R.C.; WOODS, R.E. Processamento Digital de Imagens 3 ed., Prentice Hall, 2010.
5. Huang, W., Jing, Z.: Evaluation of focus measures in multi-focus image fusion. Pattern Recognit. Lett. 28, 493–500 (2007).

6. J. Jeon et al.: Robust Focus Measure for Unsupervised Auto-Focusing Based on Optimum Discrete Cosine Transform Coefficients.IEEE Transactions on Consumer Electronics, Vol. 57, No. 1, February 2011.
7. KROTKOV, E.: Focusing. Int. J. Comput. Vis. 237, 223–237 (1987).
8. KOWA AMERICA CORP. LMZ69M Data Sheet. Available in: https://lenses.kowa-usa.com/macro-zoom-lenses/525-lmz69m.html.
9. Liu, W.-C., Yang, C.-Y.: Two-phase flow visualization and heat transfer performance of convective boiling in micro heat exchangers. Exp. Therm. Fluid Sci. 57, 358–364 (2014).
10. LETA, Fabiana Rodrigues... [*et al* .]. Metrologia por Imagem. – 1. Ed. – Rio de Janeiro: Elsevier,2016.
11. MARQUES FILHO, O.; VIEIRA NETO, H. Processamento Digital de Imagens. Brasport Livros e Multimídia Ltda., Rio de Janeiro, 1999.
12. Nascimento Júnior, Cairo Lúcio; Yoneyama, Takashi. *Inteligência Artificial em Controle e Automação.* São Paulo: Edgar Blücher: FAPESP,2004.
13. ALLIED VISION. Oscar technical manual.v2.4.0. Available in: http://www.alliedvisiontec.com/partner.html.
14. P.H.F Masotti. R.N de Mesquita. Paraconsistent Logic Study of Image Focus in Cylindrical Refraction Experiments. In: Abe J.(eds) Paraconsistent Intelligent-Based System. Springer International publishing Switzerland, 2015. Intelligent System Reference Library 94, DOI 10.1007/978-3-319-19722-7-8.
15. Ray, Sidney. Scientific photography and applied imaging. Londres: Focal Press, 1999
16. R Bitter, T. Mohiuddin and M. Nawrocki, "LabVIEW: Advanced programming techniques", 2nd ed, Taylor& Francis:London, 2006, pp.206-208.
17. Pertuz, Said. Puig, Domenec. Garcia, M. A. Analysis of focus measure operators in shape-. (2012). doi:10.1016/j.patcog.2012.11.011
18. Pertuz, Said. Focus Measure. Version 2.2.0.0, 2017. Available in: http://www.mathworks.com/matlabcentral/fileexchange/27314-focus-measure
19. Taylor, P., Ali, S.F., Yeung, H.: Experimental Investigation and Numerical Simulation of Two-Phase Flow in a Large-Diameter Horizontal Flow Line.Petroleum Science and Technology, 37–41 (2010)
20. Xu, Yupeng. Yu, Feihong. Reasearch on the image acquisition and camera control of machine vision camera based on LabVIEW. Fifth International Conference on Intelligent Human-Machine Systems and Cybernetics. (2013) IEEE DOI 10.1109/IHMSC.2013.266.
21. Zboray, R., Adams, R., Cortesi, M., Prasser, H.-M.: Development of a fast neutron imaging system for investigating two-phase flows in nuclear thermal–hydraulic phenomena: A status report. Nucl. Eng. Des. 273, 10–23 (2014)