BIOREACTOR SUPERVISION AND MODELLING USING DIGITAL IMAGE PROCESSING

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Abstract. *Bioreactors are used in order to mixture two or more components. Generally, the mixture inside the bioreactor is inspected by a technician, who watches the state of the mixture until the required homogeneity is reached. The main goal of this work is to define the time required to a set of materials, inside a bioreactor, to reach a certain grade of homogeneity. In this case, image processing techniques are applied in order to quantify the grade instead of a subjective human inspection. Since the inspection is performed, for each mixture and bioreactor types, a curve of homogeneity versus time is generated. The proposed system is able to model and to supervise a process since the parts of the material have different hue. The proposed method was evaluated using images acquired by the ICTA – (Instituto de Ciência e Tecnologia de Alimentos) – UFRGS, presenting results that confirm the relation among the hue variance histogram of the mixture and its homogeneity.*

Keywords*: Color Image Processing, Bioreactor, Supervision, Modeling*

1. INTRODUCTION

Inspection and modeling are two important fields in industrial automation. Digital image acquisition and processing techniques are being used successfully in both areas. Several processes in the food, cosmetics and drugs industries apply bioreactors in their line of production. These equipments are used in order to mixture two or more components. The state of the mixture inside the bioreactor is inspected by a technician, who must stand watching the mixture until the required homogeneity is reached.

The main goal of this work is to define the time required to a set of materials, inside a bioreactor, to reach the intended grade of homogeneity. In this case, image processing techniques are applied in order to quantify the grade instead of a subjective human inspection. Since the inspection is performed, for each mixture and bioreactor types, a curve of homogeneity versus time is generated.

The proposed system is able to model and to supervise a process since the parts of the material have different hue. The system is composed by an image acquisition system (digital camera, computer and illumination device) and software. The software is responsible to acquire the images and to handle the data extracted from the images. Figure 1 presents the general schema of the proposed system.

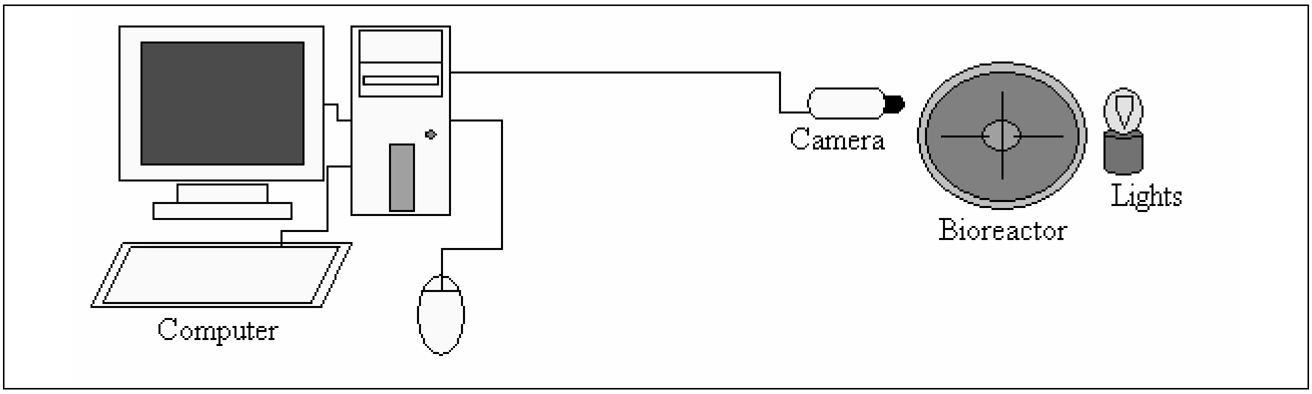

Figure 1. The system general schema.

2. THE METHOD

The proposed method is processed in five steps: a) Determination of the region of interest (R.O.I.); b) Transformation from RGB to HSI; c) Generation of the Histogram; d) Binarization; e) Evaluation. Figure 2 shows the general scheme of the proposed method.

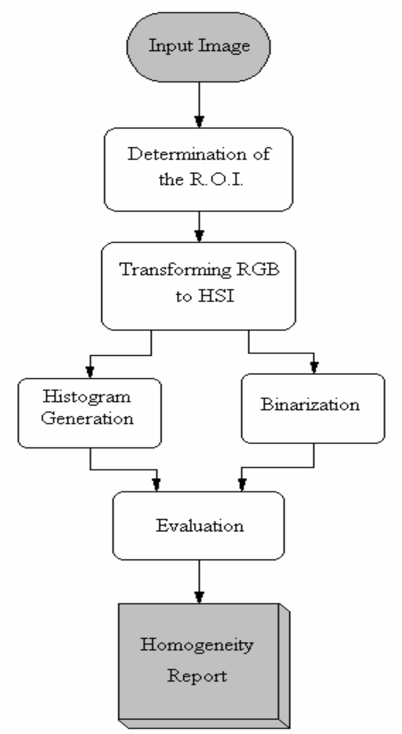

Figure 2. General scheme of the proposed method.

2.1. Determination of the Region of Interest

This step is performed only on the set up of the system. When first installing the camera at the bioreactor it is required to indicate what region should be inspected. This region of interest must be indicated including only the material under evaluation, avoiding including the bioreactor borders or parts, for instance. This calibration stage will consider a tolerance on the edge of the region due to the slight movement that the camera may suffer during the bioreactor operation.

2.2. Transforming RGB to HSI

The evaluation of color information in samples in order to be used for inspecting its composition has being successfully used in many applications [Ortiz 2005]. In order to apply this method, we needed to change the color representation space from RGB to HSI. The transforms from RGB to HSI are shown on Eq. (1-3) and the transforms from HSI to RGB are shown on Eq. (4-6) where R, G and B are the different channels information from the RGB system and H, S and I are the channels from the HIS system [Gonzales 1993].

$$H = \cos^{-1}\left\{ \frac{\frac{1}{2}\cdot\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\} \tag{1}$$

$$S = 1 - \frac{3}{R+G+B}\left[\min(R,G,B)\right] \tag{2}$$

$$I = \frac{1}{3}(R+G+B) \tag{3}$$

$$r = \frac{1}{3}\left[1 + \frac{S\cdot\cos H}{\cos(60^{o}-H)}\right] \tag{4}$$

$$g = 1 - (r + b) \quad (5)$$

$$b = \frac{1}{3}(1 - S) \quad (6)$$

Using these equations we were able to change from RGB to HIS. Its much easy to know the meaning of operations on the HSI color space, considering the information of Hue, Saturation or Iluminance, which is not clear using the Red, Green or Blue channels. The model of the RGB color space is show in Fig. 3 and the HSI color space is show in Fig. 4 [Gonzales 1993].

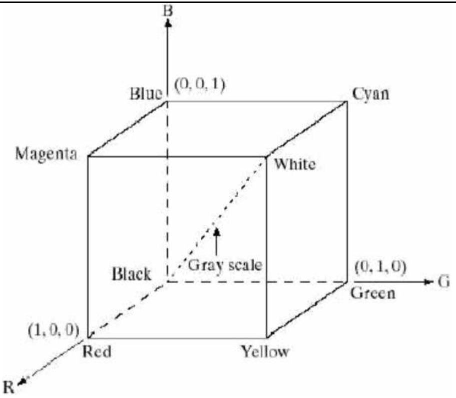

Figure 3. RGB color space model.

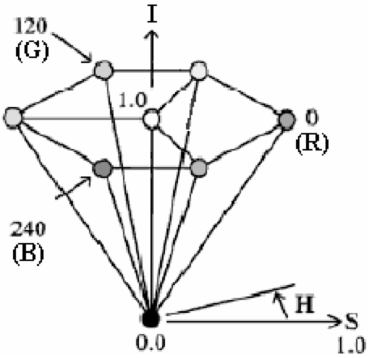

Figure 4. HSI color space model

2.3. Histogram Generation

The evaluation of the homogeneity is based on the distribution of the Hue (H component) on the image. The distribution is better evaluated on a histogram. If the histogram presents two picks, it means that there are two different colors and, therefore, the mixture is not complete. During the process, the two picks (that may be modeled by two Gaussians) approaches, becoming one pick. This indicates that the mixture is now completed. Figures 5-10 presents two examples of the process to obtain the histogram of a heterogeneous sample and the histogram of a homogeneous sample. The standard deviations for the two hue histograms are 55 and 6, respectively.

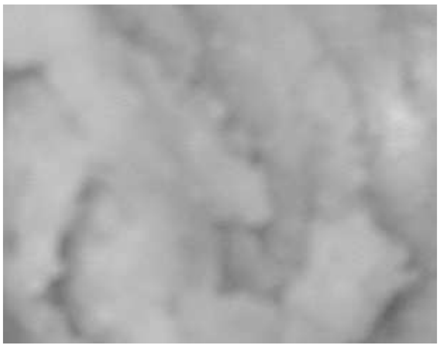

Figure 5. Heterogeneous sample.

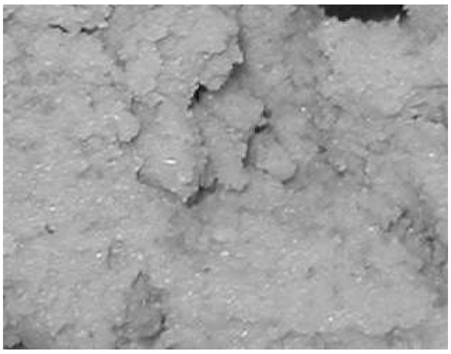

Figure 6. Homogeneous sample.

These images present only regions inside the ROI. Both samples are converted to the HIS format. Figures 12 and 13 present de Hue information of the heterogeneous and the homogeneous samples, respectively (1 degree being represented as 0.71 pixel).

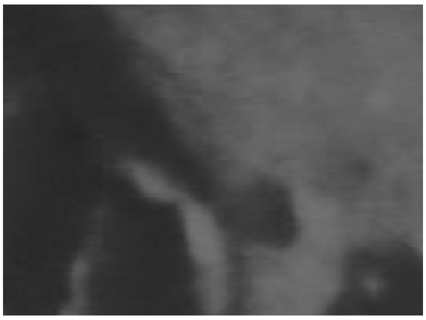

Figure 7. Hue information of the heterogeneous sample.

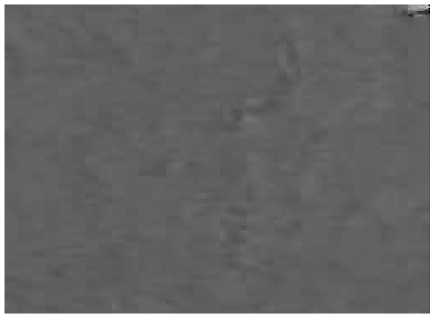

Figure 8. Hue information of the homogeneous sample.

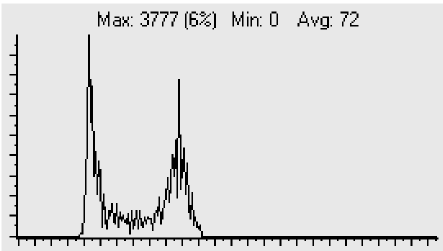

Figure 9. Histogram of a heterogeneous sample.

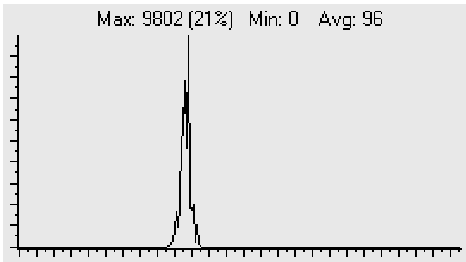

Figure 10. Histogram of a homogeneous sample.

2.4. Binarization

The illumination information is used in order to avoid errors on the color evaluation due to low color saturation on light or shadows generated by the sample itself._ The binarization is performed considering a threshold calculated (Figueiró 2003) and shown in (7)

Since the regions with poor illumination are going to be darker than the rest of the image, the region whose illumination value is under the threshold is going to be discarded from the evaluation.

The analysis proceeds by searching the first pick on the illumination histogram. Then, the second pick is searched and the standard deviation for each pick is estimated. The ilumination value with maximum value in the histogram is the μ_1; the σ_1 is calculated as eq. (7) bellow:

$$\sigma_1{}^2 = \sum_{i=1}^{N} (\mathrm{I}(i) - \mu_1)^2 \tag{7}$$

where *N* is the total number of points under consideration, I*(i)* is the value of the illumination on point of position *i*.

Then, the second peak is estimated as presented in eq. 8.

$$\sigma_2{}^2 = \sum_{i=1}^{N} (\mathrm{I}(i) - \mu_2)^2 \tag{8}$$

The σ_2 is the variance of the second peak value calculated with μ_2, that is the point of maximum value in the portion of the histogram higher than $\mu_1 + \sigma_1$. The threshold value TH is then calculated considering which peak is the darker one. In case the peak 1 is darker, than the threshold is calculated as follows:

$$TH = \mu_1 - \sigma_1 \tag{9}$$

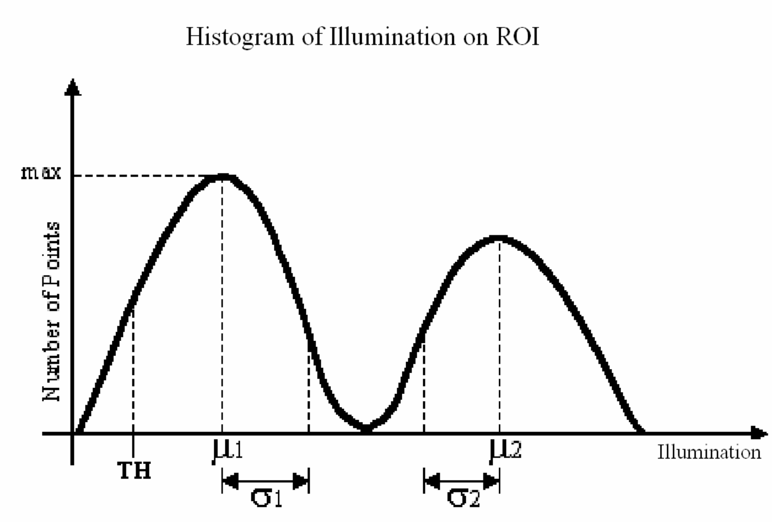

Figure 11. Model for the histogram of the correlation value at the points of minima of the flood map.

2.5. Evaluation

Using the information provided by the binarization and the Hue histogram of the sample, it is possible to estimate the degree of homogeneity of the sample.

The hue evaluation is performed by analysis of the variance of the hue histogram, without the discarded pixels on the binarization process. When a predominant hue is present in the sample, the expected histogram shape is of a Gaussian, with a small variance. When several different elements with different hue are present on the sample, the histogram shape is of several Gaussians, overlapped, with large variances.

3. EXPERIMENTAL RESULTS

The tests were performed using images acquired on the ICTA – UFRGS ("Instituto de Ciência e Tecnologia de Alimentos"). The material used to perform the mixture was soy flour (residue) divided in two masses stained with two different colors, green and yellow. The images were acquired in sequential time, while the mixing occurs. Then, images were processed according to the proposed method. Figure 12 shows the HUE standard deviation *versus* time curve.

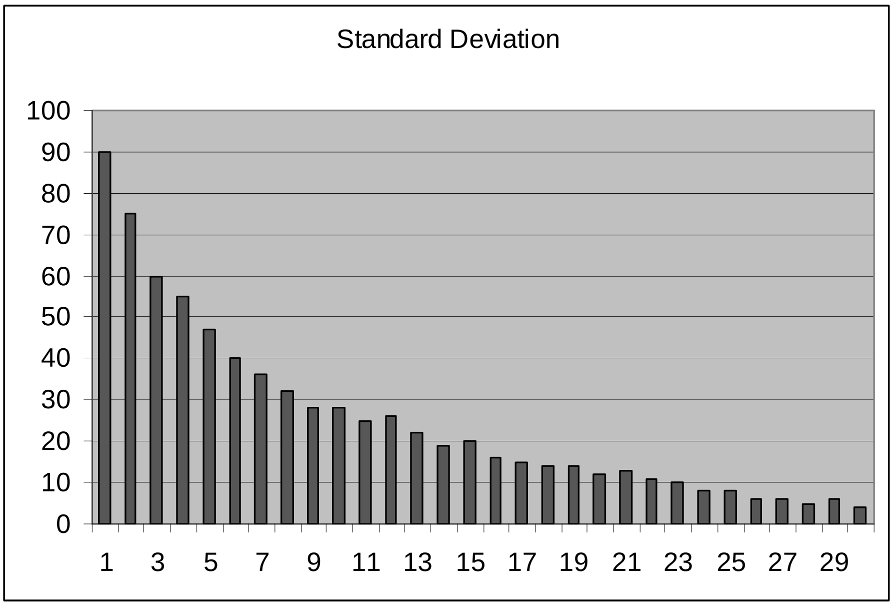

Figure 12 Hue standard deviation *versus* mixing time

4. CONCLUSION

In this paper we proposed a method for evaluating the degree of homogeneity of a mixture inside a bioreactor. The color space transform was used to generate the hue information, that was successfully used to evaluate the homogeneity.

The proposed method shown results compatibles with the technical reports provided by engineers from the ICTA, a food technology research laboratory from UFRGS. The hue standard deviation *versus* mixing time curve represents properly the bioreactor – material mixing behavior, therefore it can be used as a model for automation the inspection and control the mixing process.

Furthermore, the use of a non-expensive acquisition system makes the proposed method a low cost system and a simple technique of thresholding avoided the non-uniform distribution of light, usually present when low cost cameras are used.

The use of the *lili* [Lili 2005] library to test algorithms and to develop the software reduced the time required to generate the system.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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