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METALLIC PARTICLE DETECTION IN LUBRICANT OIL USING IMAGE PROCESSING

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Abstract. *Lubricant analysis is on of the most efficient methods to reduce the productivity loss while the factory machines are stopped. The preventive maintain, that consists in periodically evaluate the lubricant oil, brings a reduction of 50% of the equipment usage in a high scale production. This is the main reason for developing an efficient and automatic method to evaluate the contamination of the lubricant. Visual evaluation is made in order to analyze the conditions of the oil, and filters are installed in the lubricant ducts to present a qualitative analysis. The problem of this technique is the importance of the operator experience and training. This work propose the use of image processing techniques over the image of the membrane used as filter, in order to detect and quantify metallic particles deposited on it. The proposed method uses color space transforms and pattern recognition on the image hue. The method results were evaluated by engineers of the GPFAI – UFRGS and by engineers of the ENGEFILTRO Company, that provided reports of the processed samples. The proposed method presented results that confirm the concentration report.*

Keywords*: Lubricant analysis, preventive maintain, image processing and color space transforms*

1. Introduction

The different kinds of mechanical wastage in hidromechanical systems are: adhesion, fatigue or glowing. Each of these kinds is attributed to the interaction of pieces with metallic particles that are loosened from the machine and get in suspension on the lubricant fluid [Engefiltro 2003, Moura 1978].

The methods in use to measure the contamination (existence of non-wanted particles) on a lubricant are many. Basically, these methods consist on filtering membranes insertion on the fluid ducts and in evaluation of the material displaced on it. Two of the most accurate methods are the Optical Visual Counting and the Automatic Counting. The Optical Visual Counting is made in a laboratory by a technician that observes the quantity and size of the metallic particles in a membrane sample used as oil filter. In this case, a magnifying glass with 40x gain is used to the analysis.. The Automatic Counting presents more accurate answers but requires more expensive equipments, time and frequent calibration [Engefiltro 2003, Moura 1978].

This work proposes the use of image processing techniques to analyze the lubricant contamination. The system is automatic and has low cost features, based on color analysis to detect particles in digital images of the filter sample.

The results presented were obtained using two different acquisitions setups. The first applies a low cost acquisition system developed at LaPSI named SAIMO [Figueiro 2003b, Schuch 2004] that consists on a camera connected to a microscope and then we compare with the result we obtained using a setup with a scanner. In both cases we transformed the color space from RGB (Red, Green and Blue) to HIS (Hue, Saturation and Intensity) in order to analyze the hue to detect the particles of metal in the filter membrane. The software was developed using the *lili* - LaPSI Image Proessing Library (*Lili*).

2. Proposed Method

In this work we use the incident light reflection. In this case two main cases appear: How the light reflection appears in the acquired image and how we could identify it by image processing [Gonzales 1993]. The images acquired as samples shown that the light reflection presents different shapes for different acquisitions systems. In this work we used two different acquisition systems available at LaPSI, the SAIMO [Figueiro 2003b, Schuch 2004] and a scanner.

The proposed method is based on color space transforms, definition of a Region of Interest (R.O.I.) and a binarization considering the hue value of the particles and of the background. The Proportion Evaluation is made by comparing the number of particle pixels with the R.O.I pixels; the Map of Regions consider the number of particles even when they have different areas [Figueiro 2003a, 2004]; the Histogram Generator evaluate the distribution of hue in the particle pixels. The proposed method scheme is shown in fig. 1.

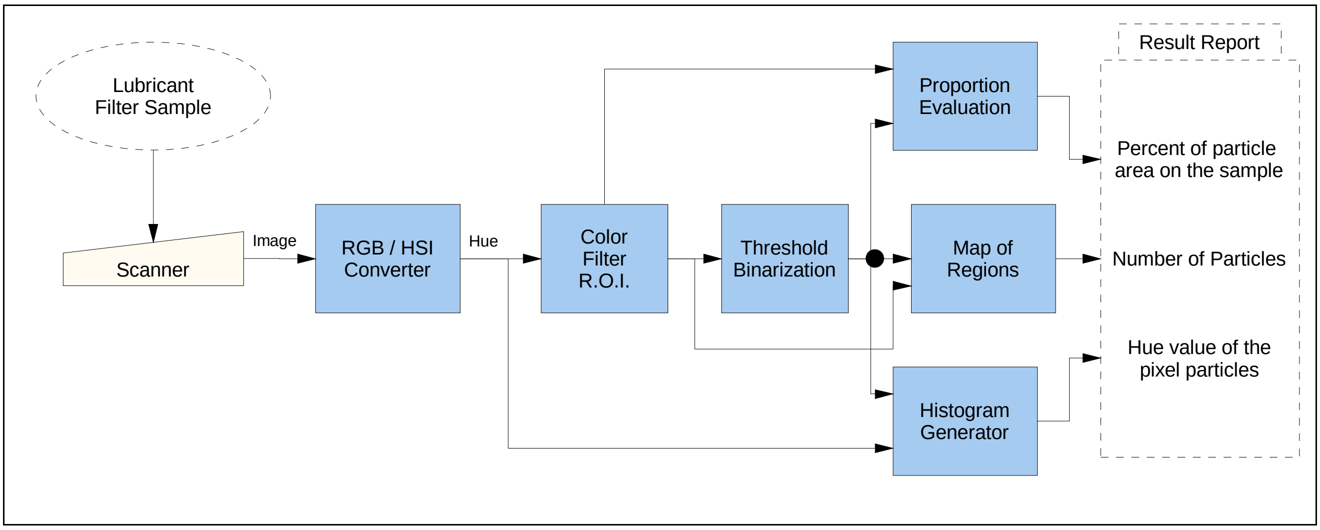

Figure 1. The general scheme of the proposed method

2.1. Acquisition using the SAIMO

The SAIMO ("Sistema de Aquisição de Imagens para Uso em Microscopia Óptica" – Image Acquisition System of Optical Microscopy Use) is a low cost system for image acquisition and treatment. The system is composed by an acquisition hardware and software. The image sensor is based on a 640x480 resolution web cam and is connected to a computer throws the USB interface. The software was developed for Windows and has functions to acquirer, aid the acquisition and image processing. The functions were developed using the *lili* (*Lili)*. Figure 2 shows the SAIMO [Figueiro 2003b, Schuch 2004] system at LaPSI.

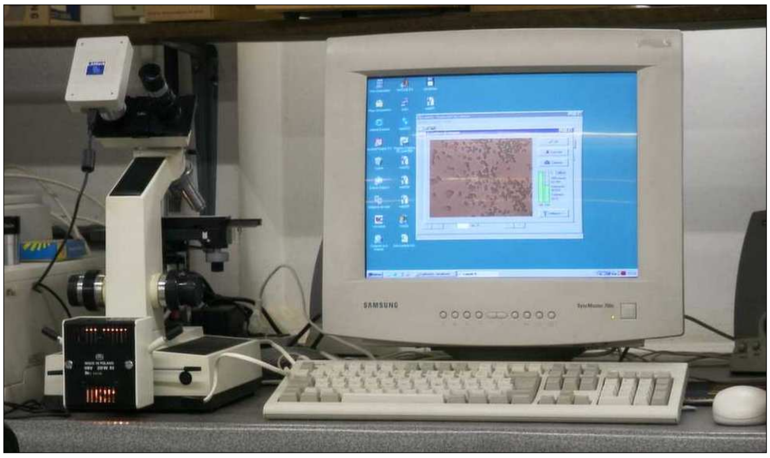

Figure 2. The SAIMO system at LaPSI

The acquired images by the SAIMO shown that the reflected light was captured by the camera sensor as high luminance and blue hue. Although, the microscopy used illuminates the object by a non uniform way, which makes the detection dependent of the light source position. In order to verify this sensibility, two different acquisitions of the same region were made, with the only difference was the position of the light source. Figs. 3 and 4 show the acquisitions of the same sample. Is ease to notice that in Fig. 3 there are some particles that do not appear at Fig. 4. The random shapes of the particles make them reflect only the light that comes from a specific direction. Figure 5 shows the difference between the two acquisitions (Fig. 3 and Fig. 4), revealing a large number of shinning points (points of higher luminance) that are not coincident. This problem could be solved by applying a uniform illumination.

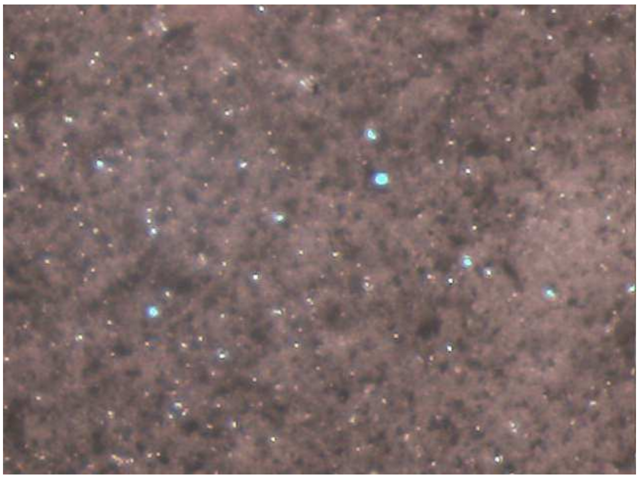

Figure 3. Image acquired using one illumination direction.

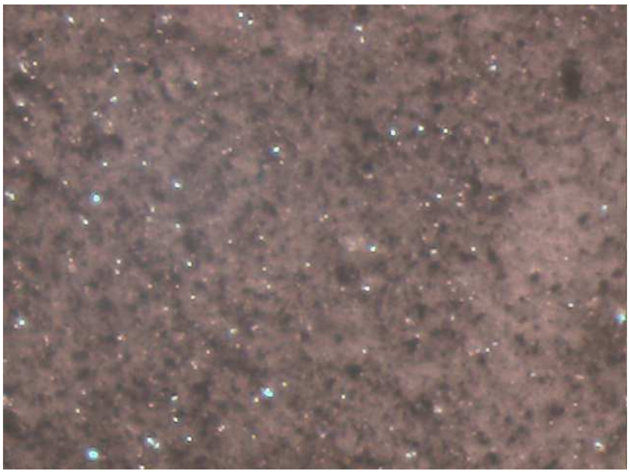

Figure 4. Same region, illuminated from a different direction.

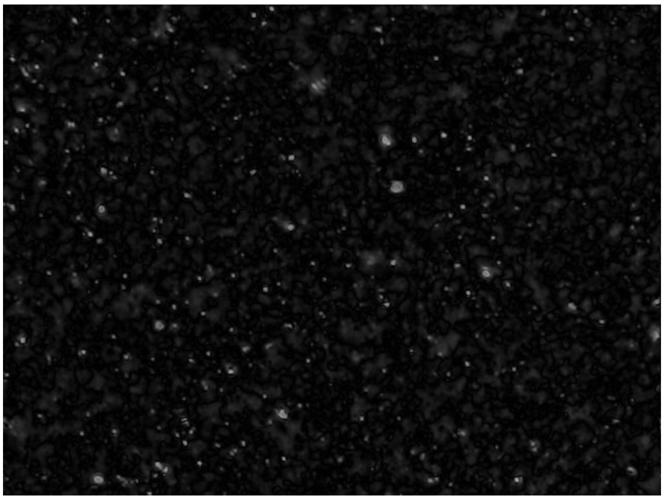

Figure. 5. The difference among Fig. 3 and Fig. 4.

2.2. Acquisition using Scanner

The problem of non uniform illumination presented using any microscopy system, as the SAIMO, is not presented when a scanner system is used. The scanner used was the Canon CanoScan N676UIN1240U, using a resolution of 1200 dpi.

Figures 6 and 7 presents images of two different membranes used as oil filters of an industrial equipment under tests. Figure 6 shows the result of a oil with few usage and, consequently, low metal concentration. Figure 7 presents the result of using a oil with a long time usage. Both filters have 50mm of diameter.

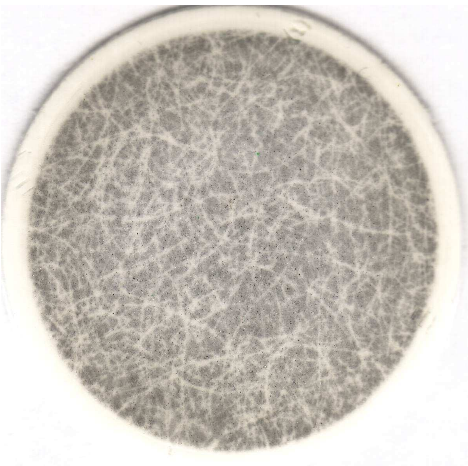

Figure 6. Membrane with low density of metal.

Figure 7. Membrane with high density of metal

The images acquired from a scanner do not present points of high luminance (corresponding of the light reflection on the metallic particles), as presented using the SAIMO. For this reason, images as show in Fig. 6 and Fig. 7 do not show any information about the particle besides its density in the oil [Vital 2004]. Nevertheless, the variation of the color on the samples (not easy to notice just looking at the samples) is clearly seen using some image processing, as color space transforms.

2.3. Color Space Transforms

The analysis of the acquired images began with the color characteristics enhancement, using a stretch method over the saturation [Vital 2004]. In order to apply this method, we needed to chance the color representation space from RGB to HSI. The transforms from RGB to HSI are explained on Eq. (1-3) and the transforms from HIS 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].

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

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

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

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

$$g = 1 - (r + b) \tag{5}$$

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

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. 7 and the HSI color space is show in Fig. 8 [Gonzales 1993].

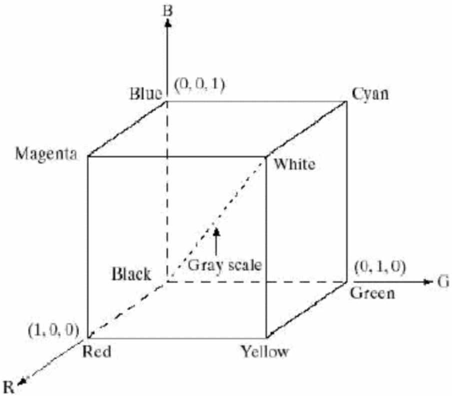

Figure 8. RGB color space model.

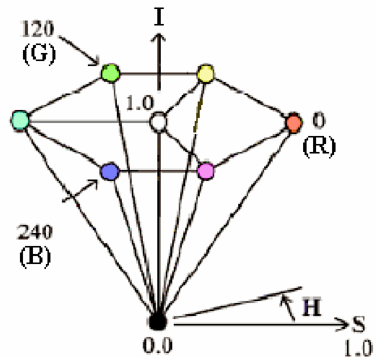

Figure 9. HSI color space model

In order to analyze the membranes in the color space HSI, the saturation value was set to the maximum value possible (S = 1). To visualize an image, it is necessary to convert it back to the RGB color space. Figures 10 and 11 shows the results of applying this process on the images shown in figs. 6 and 7.

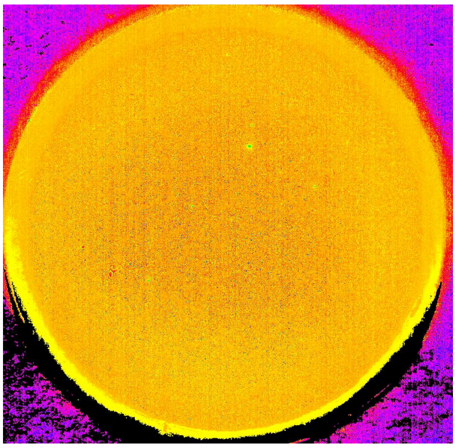

Figure 10. Image from fig. 5 with maximum saturation.

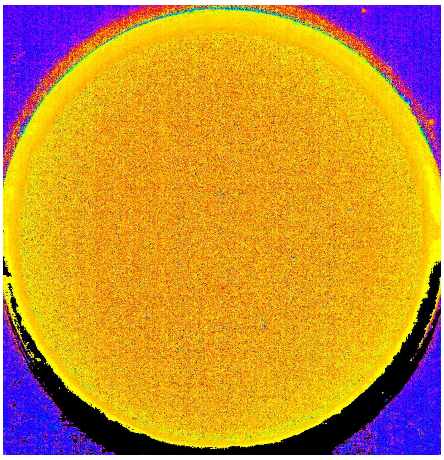

Figure 11. Image from fig. 6 with maximum saturation.

2.3. Color Analysis

Zooming the images shown in figs. 10 and 11 we are able to analyze some particularities considering the variation of existent colors. Amplified view of those images are shown in figs. 12 and 13.

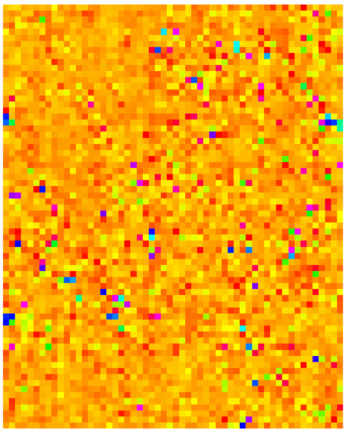

Figure 12. Membrane with low concentration of metallic particles.

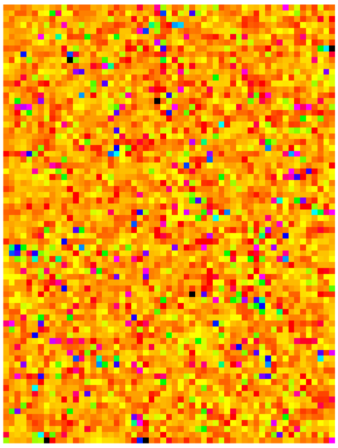

Figure 13. Membrane with high concentration of metallic particles.

Analyzing the images on fig. 11 and 12, we notice that the color of the membrane is essentially orange (H = 30º), in a range from the red (H = 0º) to the yellow (H = 60º) (Vital). Nevertheless, elements of different colors may be found. For instance, blue elements (H = 240º), cyan elements (H = 180º), green elements (H = 120º) and magenta (H = 300º). On fig. 13 exists more elements from H = 180º to H = 300º than in fig. 12. In order to better visualize this comparison, we generated binary images considering black every element which hue value were from -30º (330º) to 90º and white to the others. Figures 14 and 15 show the results.

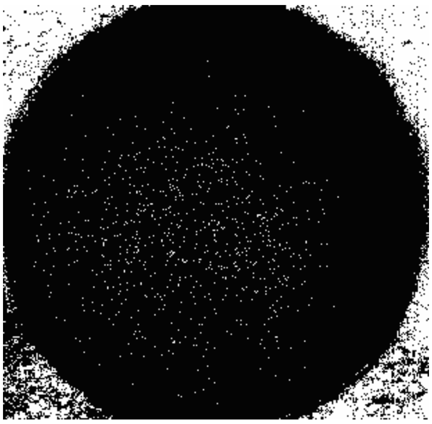

Figure 14. Membrane with low concentration of metallic particles.

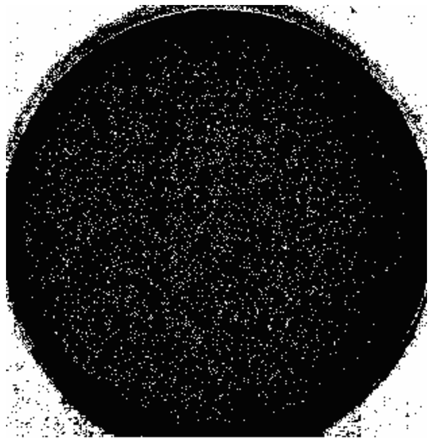

Figure 15. Membrane with high concentration of metallic particles.

3. Experimental Results

The samples used to develop the algorithms and test were provided by the company Aracruz Celulose. This company studies and provides oil contamination reports for many industries all over Brazil.

In order to implement the software to apply the proposed method, we used the *lili* (LaPSI Image Processing Library) [Lili 2005] that provides many image processing functions. The software was built using C++ language. An interface of the software is shown in fig. 16.

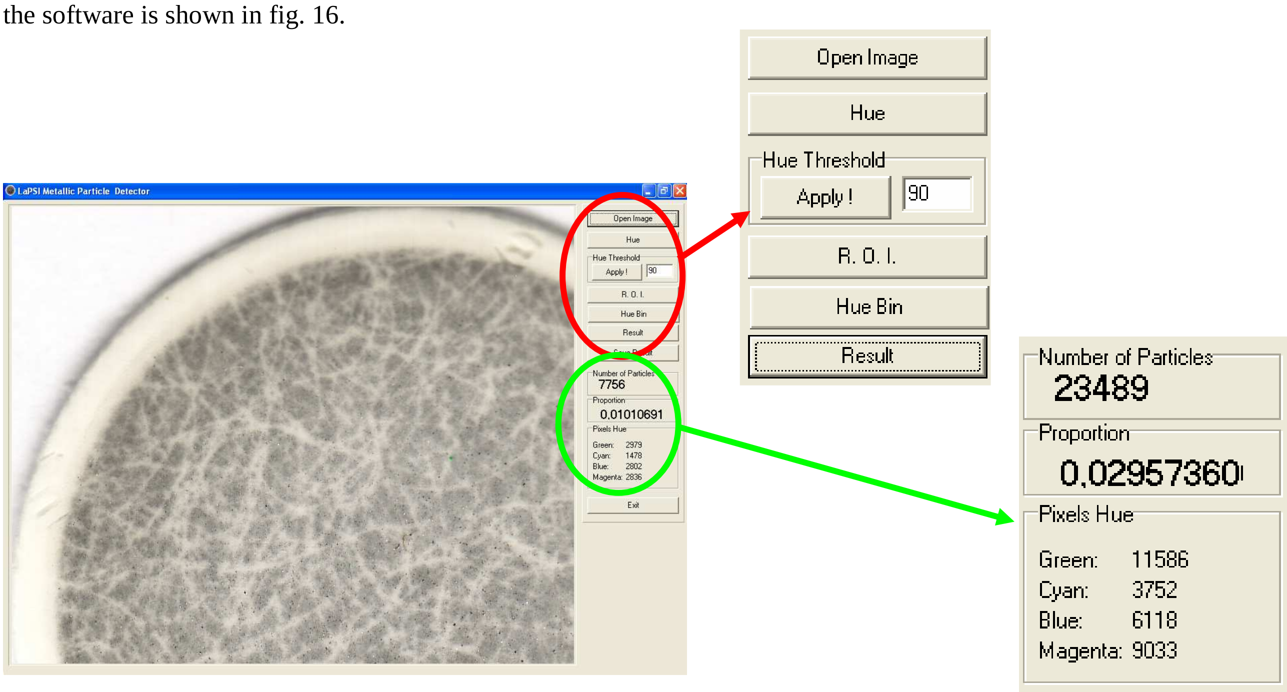

Figure 16. The software interface. In detail, the command buttons and the results report.

The results presented in this section consider only the samples acquired using the scanner as acquisition system because the results acquiring the images using the SAIMO only served to prove that system with non-uniform light incidence causes variable results for different positions of the same sample.

Using the scanner set up, we applied the proposed method in the two samples shown in figs. 6 and 7. The results are show in Tab. 1.

Table 1. Experimental results for two samples of oil filter membranes

Membrane	Particles Counted	Total of Pixels	Proportion Considering Membrane Size
Low Concentration of Metallic Particles	7756	10095	0.0101069 (1.0107 %)
High Concentration of Metallic Particles	23489	30489	0.0295736 (2.9574 %)

We also decided to consider the distribution of the particle colors, in order to evaluate the possibility of the usage of color information to classify the particles (age, material, etc.). The colors were evaluated in bins in order to consider the main color. The bin size was of 60º, taken 30º before and 30º after the value of a color. The result for the images in fig. 6 and 7 are shown in Tab. 2.

Table 2. Hue evaluation in the samples

Hue Value	Low Concentration	High Concentration
Green (90º to 150º)	2979	11586
Cyan (150º to 210º)	1478	3752
Blue (210º to 270º)	2802	6118
Magenta (270º to 330º)	2836	9033

The results showed on Tab. 2 may be useful to qualify the particles (age, material, etc.). The colors were evaluated in ranges in order to consider the importance of each main color group in the distribution. Figure 17 shows in columns graphs these distributions.

We also evaluated the proportion of each hue group in the total number of particle pixels to evaluate the differences in colors from a low concentration of metal to a high concentration of metal in a membrane filter. Figure 18 shows in pizza graphs these results.

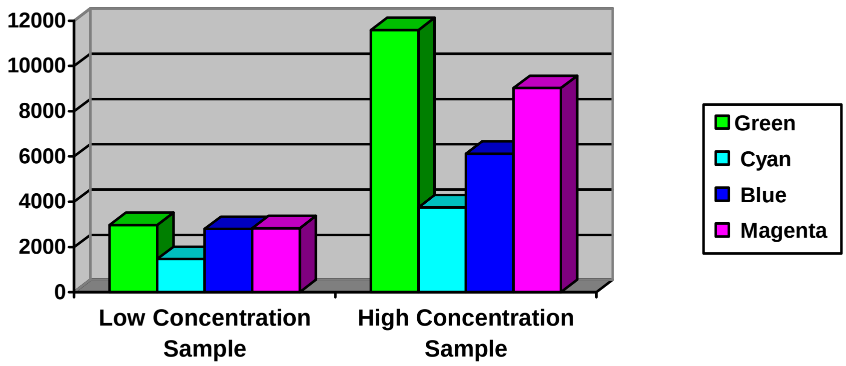

Figure 17. Graph of incidence of hue in the particle pixel on the Low Concentration Sample and on the High Concentration Sample

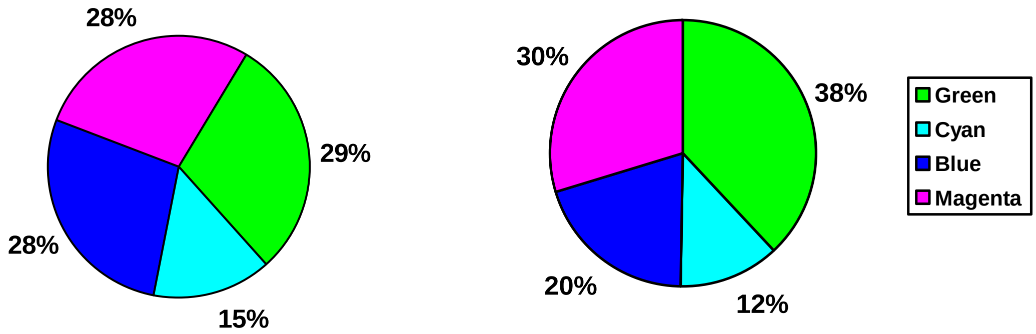

Figure 18. Pizza graphs of proportion of each hue group in the total number of particle pixels in the low concentration sample and the high concentration sample

4. Conclusions

In this paper we proposed a method for counting metallic particles in lubricant oils using image processing technics. The color space transform was used to generate the hue information, that was successfully used to detect particles even when the R, G and B channel values were very similar.

The proposed method showed results compatibles with the technical reports provided by engineers from the LABMECFRAC, a mechanical research laboratory from UFRGS and engineers from the ENGEFILTRO, a company that evaluate samples from many industries all over Brazil.

Furthermore, the use of a commercial scanner makes the proposed method a low cost system and avoided the non-uniform distribution of light, presented in systems based on microscopes or magnifying glasses.

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

The next step of this research is to qualify the metallic particles using information provided by the hue information and by other algorithms. The particles may be classified by their size, but the use of a higher resolution set up will be required.

5. Acknowledgements

This research was partially financed by Fapergs and CNPq.

Special thanks to the engineer Antônio Silveira – Aracruz S/A, for providing the samples to analysis.

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