MODELING OF TEXTURE AND COLOR FROTH CHARACTERISTICS FOR EVALUATION OF FLOTATION PERFORMANCE IN SARCHESHMEH COPPER PILOT PLANT USING IMAGE ANALYSIS AND NEURAL NETWORKS

N. Saghatoleslam, H. Karimi and R. Rahimi

Department of Chemical Engineering, University of Sistan and Baluchestan
Zahedan, Iran 98164
psaghatoleslami@yahoo.com - Hajirk@yahoo.com - Rahimi@hamoon.usb.ac.ir

H. H. A. Shirazi

Department of Mining Engineering, University of Bahonar
Kerman, Iran

(Received: January 4, 2003 - Accepted in Revised Form: June 10, 2004)

Abstract Texture and color appearance of froth is a discreet qualitative tool for evaluating the performance of flotation process. The structure of a froth developed on the flotation cell has a significant effect on the grade and recovery of copper concentrate. In this work, image analysis and neural networks have been implemented to model and control the performance of such a system. The result reveals that these techniques can be employed to control the performance of flotation cells, improve the recovery of the copper concentrate and finally reduce the dependency of the performance on the solely observation of an operator which can be otherwise subjected to human error.

Key Words Froths Flotation, Digital Image Processing, Copper Concentration, Neural Networks

چکیده بافت ظاهری و رنگ کف بعنوان یک معرف کیفی مناسب نقش مهمی در ارزیابی عملکرد فرآیند فلوتاسیون ایفا می‌کند. ساختار کفی که در سلول فلوتاسیون تشکیل می‌گردد اثر مستقیمی در درجه بازیافت کنسانتره مس دارد. بنابراین در این پژوهش از روش آنالیز تصویری و هوش محاسباتی (شبکه های عصبی) بمنظور مدل سازی و کنترل فرآیند فلوتاسیون استفاده گردیده است. نتایج حاصل نشان می‌دهد که از این روشها می‌توان برای کنترل و عملکرد سلول فلوتاسیون، بهبود بازیافت کنسانتره مس و در نهایت کاهش اتکاء به تنها نگاه چشمی اپراتور – که ممکن است دارای خطا باشد – استفاده نمود.

1. INTRODUCTION

The structure of froth developed on the flotation cell surface, have a direct effect on the performance of such a system. However, evaluation of froth may not be an efficient way to be interpreted by only an operator observation. The system performance is highly dependent on the morphology of the surface froth, which can be influenced by the degree of the operator skills [1]. In recent years, on-line monitoring of the froth flotation phase has attracted the interest of numerous researchers [2-4]. The output of a machine vision system has given new research insight into the system that has previously been determined by an operator. The results of off-line analysis can be combined with the stored images and features extracted previously. This can contribute to more efficient interpretation of the system and hence upgrading the performance of the cell. Now a day, neural networks are widely recognized for their ability to interpret pattern-based information. In the present study, an appropriate and robust algorithm with a combination of reduced noise filters, edge detection functions (i.e., Laplacian and Roberts)

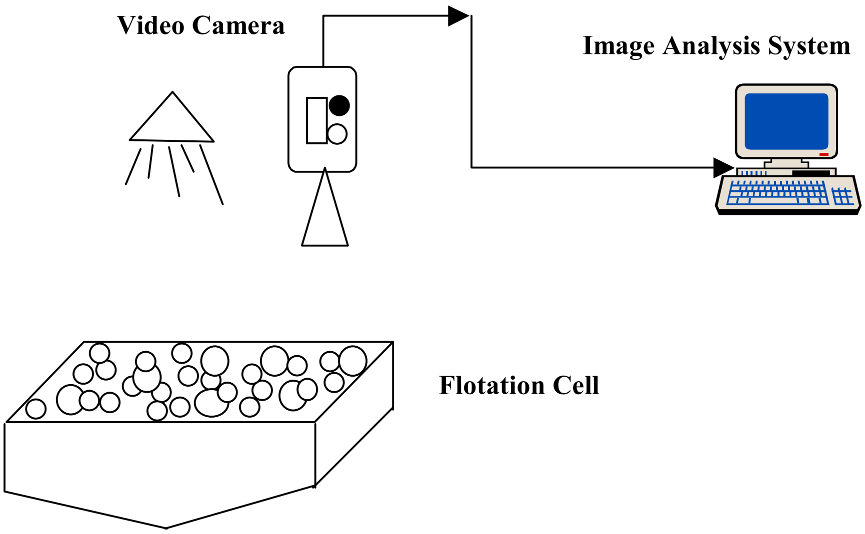


Figure 1. Schematic diagram of image capturing of the cell surface froth.

and different mathematical morphology models (i.e., Erode and Dilate) have been adopted [5]. Hence, we analyzed the structure of the surface froth (i.e., the bubble size, bubble size distribution and bubble shape factor). In addition, interpretation of surface froth colors has been implemented by adopting HSL (Hue, Saturation and Luminance) techniques. Furthermore, neural networks method has been used to correlate between the froth characteristics and flotation process performance.

2. EXPRIMENTAL SET-UPS AND PROCEDURE

In order to establish some measures for the evaluation of the surface froth structure, the images coming from a video camera installed over the flotation cell was directed to a computer are used to process the data. In Sarcheshmeh copper pilot Plant the throughput of the ore was about 1.6 ton/d, particle size of about 70 percent under 200 mesh and Cu grade of input and final concentrate of about 1 and 28 percent, respectively. The collectors (R407 and Z11) and frothers (MIBC and A65) utilized in this case were chosen according to the morphology of the ore.

Figure 1 shows the schematic diagram of the cell froth. It incorporates a set of video camera, which can take picture both digitally and in an analog manner. Simultaneously, sampling from cell concentrate was curried out in order to determine the froth mineral compositions (i.e. CuO, Fe, Mo and Cu) and water flow rate. Moreover, in order to establish the grade of the concentrate for the copper and iron, about one hundred samples were taken from the over flow cells. Furthermore, to reduce over segmentation of bubble surfaces for the analysis, camera and the spotlight were set perpendicular to the cell. In order to determine the surface froth indices (i.e., bubble size, bubbles distribution and a set of criterion for the shape of bubbles), an algorithm was constructed. The basic parts of the analysis involve: pre-filtering (image enhancement), image segmentation and parameterization. To achieve and enhance a distinct brightness for the bubble boundaries, mathematical morphology function has been adopted. In addition to reduce light diffraction and obtain better quality pictures

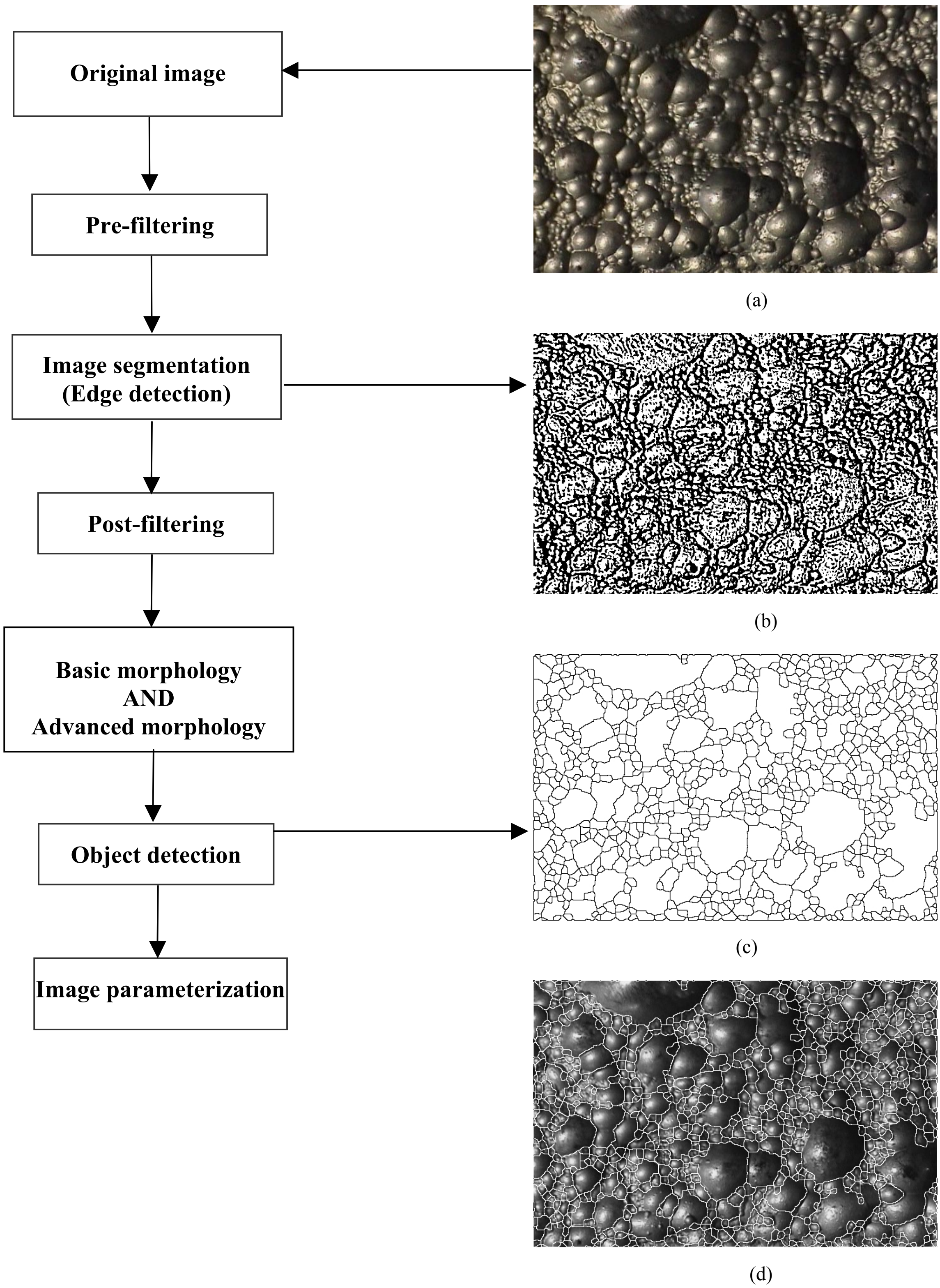
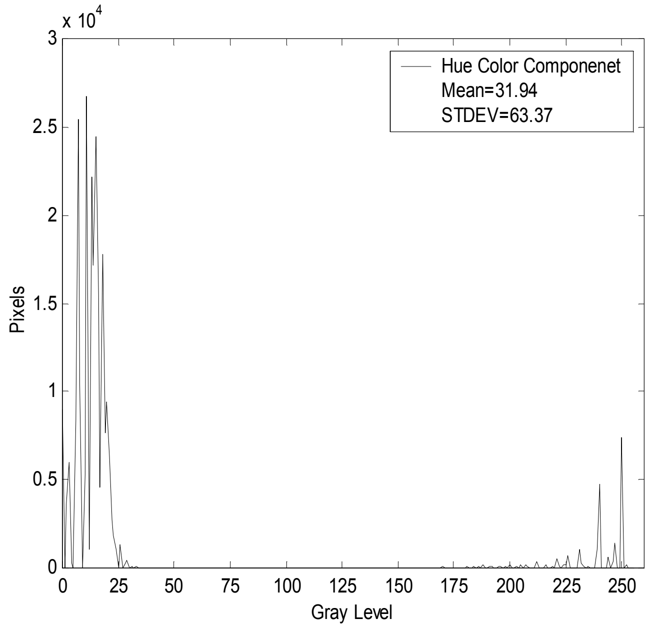
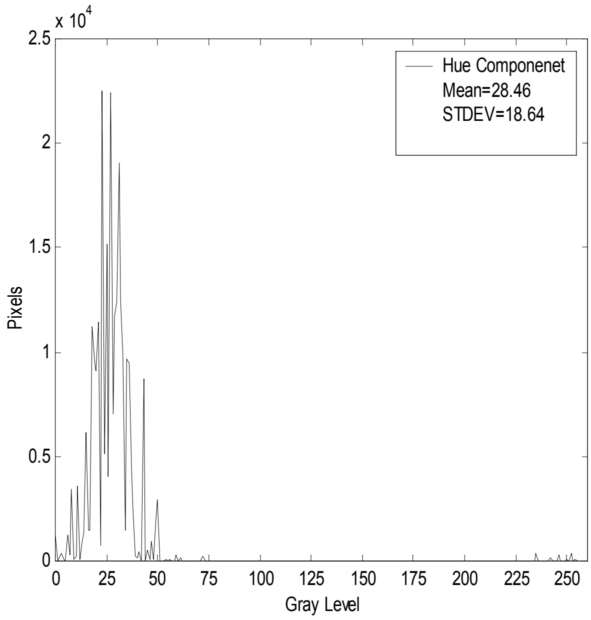


Figure 2. Block diagram image analysis: **(a)** original image, **(b)** segmented image, **(c)** morphology prediction of bubbles. and **(d)** overlapping of original and predicted images.



(a)



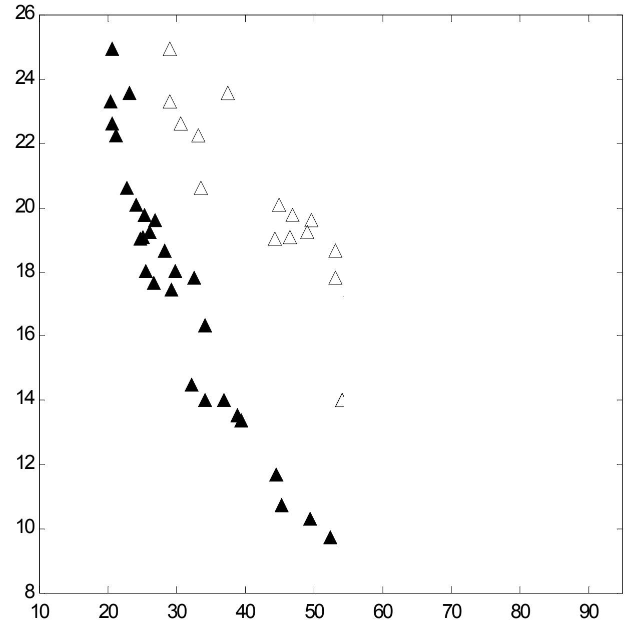
(b)

Figure 3. Histogram diagrams of H component for: (**a)** low grade bubble image copper concentrate and (**b)** high grade.

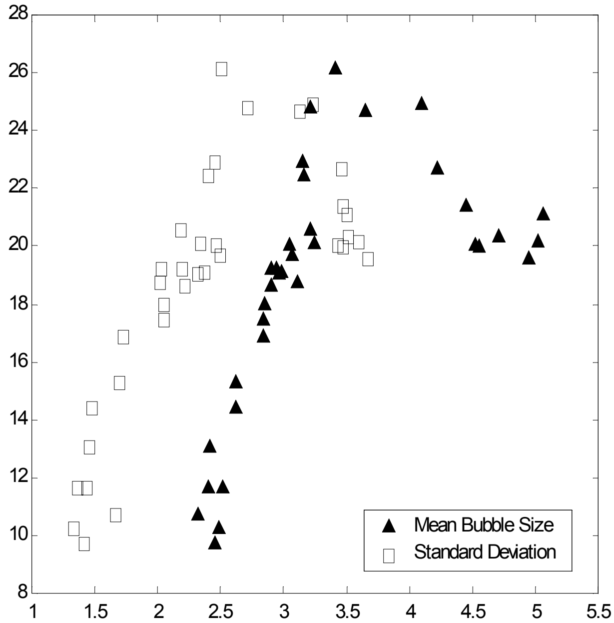
for pre-processing, different filters have been utilized [6]. Therefore, homogenous light distribution has been applied on the bubble surfaces and boundaries, which could prevent image over segmentation. To detect bubble boundaries, a combination of edge detection function and mathematical morphology function has been adopted. Finally, different indices for the surface froth texture (i.e., bubble size, size distribution and the degree of sphericity) have been selected. In Figure 2, a sequence of block diagrams image analysis with its effects on the surface froth images have been demonstrated. To analyze colors, color distribution histogram with respect HSL reference (Hue, Saturation and Luminance) must be plotted. From these figures, the mean and standard deviation of the color can be estimated. A typical color distribution of the image (H component) has been exhibited in Figure 3.

3. RESULTS AND DISCUSSION

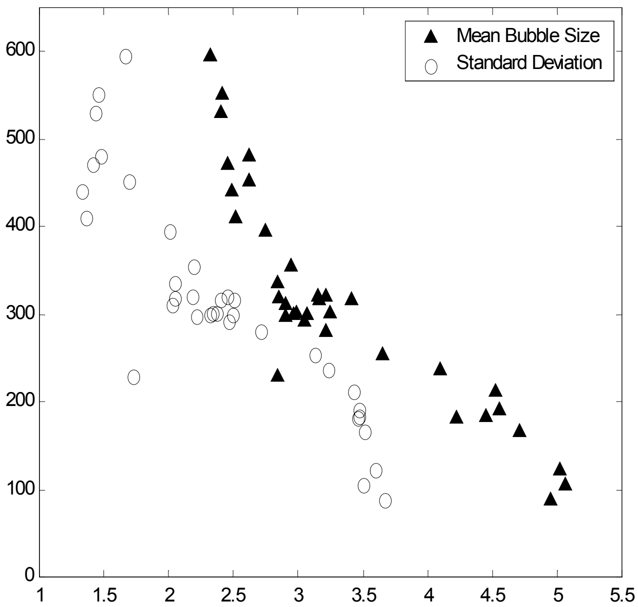
The surface froth color conveys information about the mineral species and concentration in surface froth. Therefore, representation of color can be shown in terms of RGB (Red, Green and Blue) or HSL (Hue, Saturation and Luminance) reference. Since in RGB reference, all the three components are needed simultaneously and in HSL reference only H component is required to specify the color. Therefore, adopting RGB has no polarities over HS color reference. Hence, this HS distinction has led to its usage in most image processing applications [5]. For HSL color histogram, different parameters can be estimated (i.e., mean color component with the standard deviation). Amongst them, parameters relating to H components show a good agreement with the grade of the concentration of copper and can be utilized for identifying the colors. Figure 4a shows



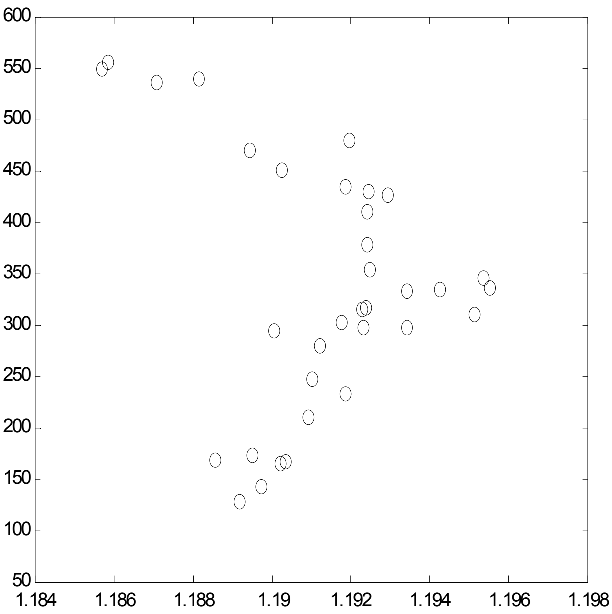
(a)



(b)

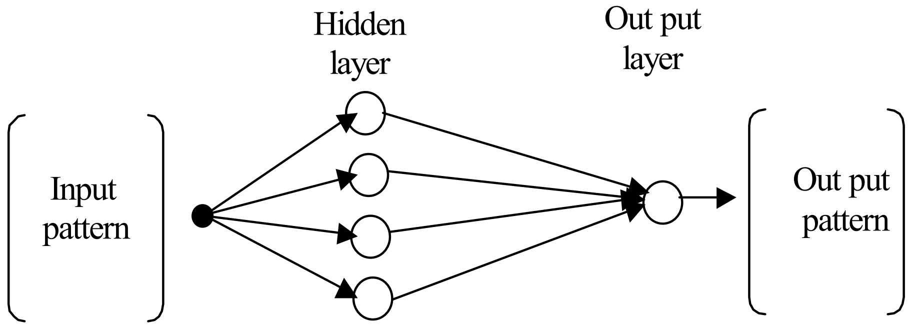


(c)

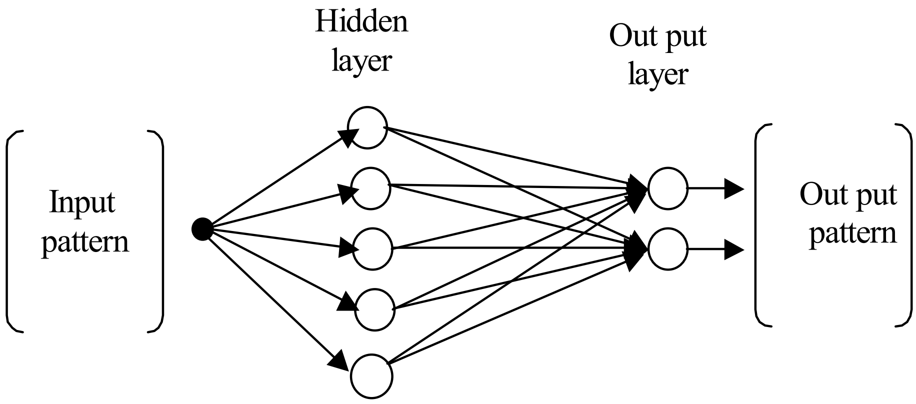


(d)

Figure 4. (a) Relationship between the copper grade and H color component, (b) variation of copper grade with the surface froth bubble size, (c) variation of solid mass flow rates with the surface froth bubble size and (d) variation of solid mass flow rates with the degree of the sphericity of the froth bubble size.



(a)



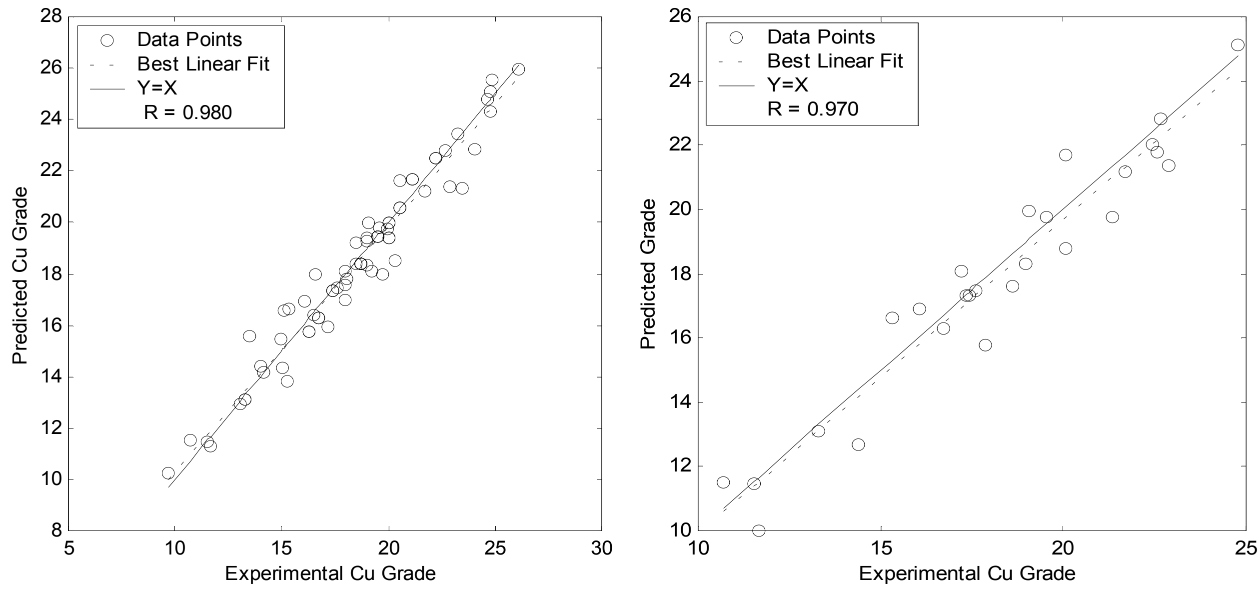
(b)

Figure 5. (a) A 6:4:1 structure of neural networks for modeling surface froth characteristics from the copper grade or its mass flow rates and (b) a 6:4:2 structure of neural networks for modeling surface froth characteristics from the copper grade and its mass flow rates.

the relationship between the mean color component and its standard deviation with the grade of copper concentrate. In the case where the grade of copper concentrate was high, the surface froth was almost uniformly distributed with the minerals. Hence, as shown in the above figure, the standard deviation of color is relatively low. On the contrast, in the case where the grade of the surface froth concentrate was low, the value of standard deviation would be relatively higher. This is caused by the ore particles of the froth, which was not uniformly distributed. This phenomenon will be enhanced if the ore particle is reduced on the bubble surfaces (due to reduction of the light reflection from the surface froth). This phenomenon can be visualized as peaks (in the above figures) and are appeared at approximately 200-255 gray levels.

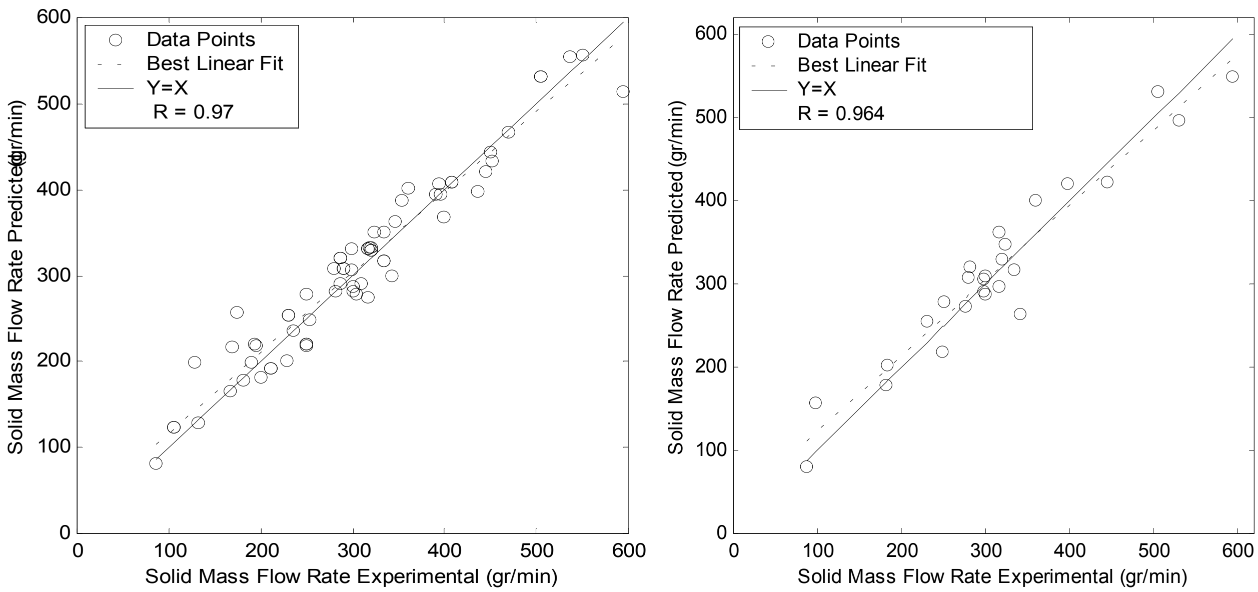
In the case where the froth sulfide enriched with calcopyrite, location of color peaks occurs at approximately 35-43 gray levels and can alter depending on the amount of pyrite and copper in the froth. However, in the case of calcocite ores, this location is still further reduced to approximately 17-22 gray level. In addition, if the surface froth is low both in grade and particle size, the extension of the range of peaks occurrence will be increased accordingly.

Bubble mean size and its sphericity in coupled with its distribution can be implemented in



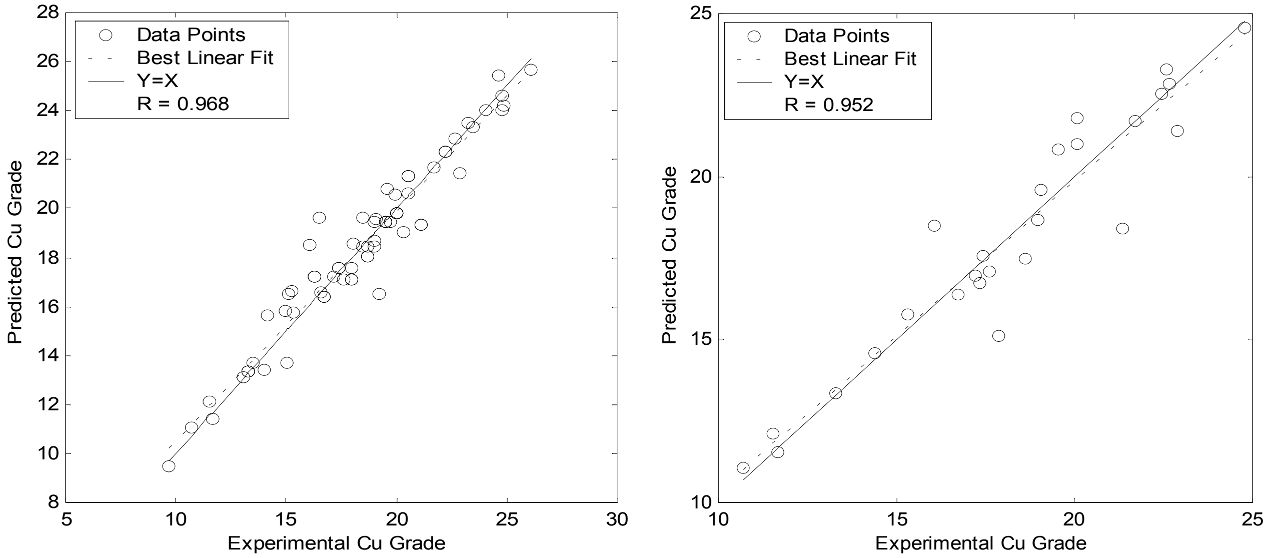
(a) (b)

Figure 6. Predicted performance of copper grade for a 6:4:1 trained neural networks for: (a) training data and (b) test data.



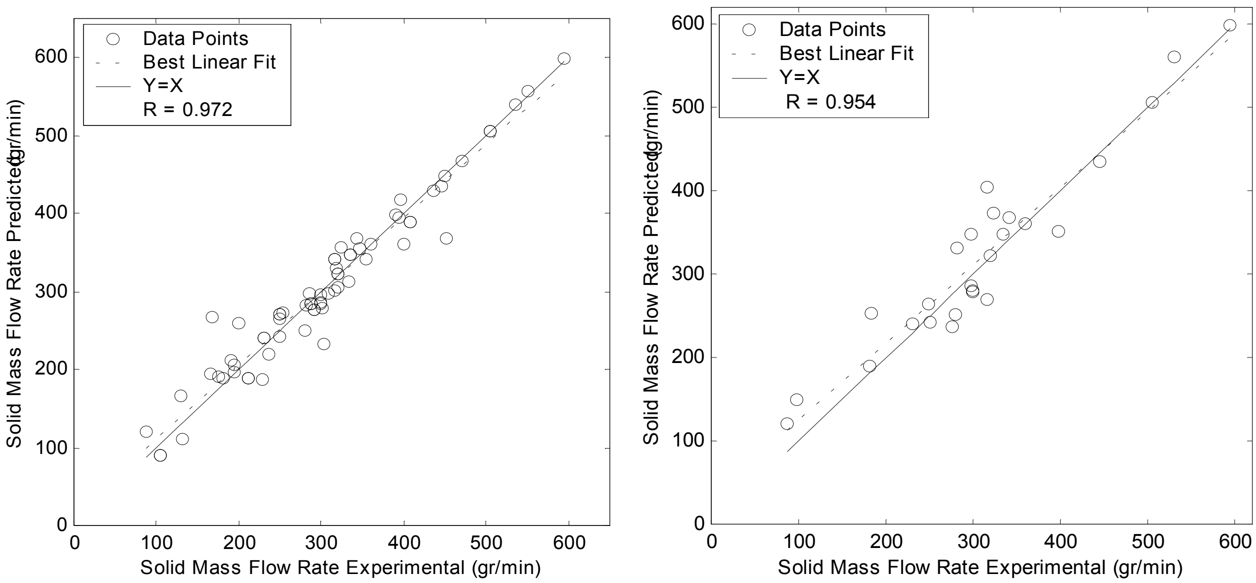
(a) (b)

Figure 7. Predicted performance of mass flow rates for a 6:4:1 trained neural networks for: (a) training data and (b) test data.



(a) (b)

Figure 8. Predicted performance of copper grade for a 6:4:2 trained neural networks for: (a) training data and (b) test data.



(a) (b)

Figure 9. Predicted performance of mass flow rates for a 6:4:2 trained neural networks for: (a) training data and (b) test data.

manifestation of bubble image structures. The variation of these parameters with the performance of the cell at the peripheries of specified location (i.e., 18 percent copper concentrate) can be observed in Figures 4b-4d. Altering the conditions (e.g., throughput of frother, collector and the aeration rate) can cause two different regions in terms of bubble size and grade of the concentrate. Generally speaking, an increase in the amount of frother tends to remain the size of the bubbles unwavering. Hence, causing the bubble become more spherical in shape (i.e., bubble circularity factor tends to 1). On the other hand, an increase in the amount of collector can gradually increase the bubble size and the grade of the concentrate [7]. However, additional increase in the collector input amount would reduce the grade of concentration and the tendency of bubble to grow bigger. Other workers also observed these trends [8]. It is also of interest to note that, in this region, as the amount of collector increases, the bubbles tends to become more spherical in shape [7]. In addition, an increase in the amount of the frother will give the same trend as the above case but with a higher value. Furthermore, variation of the aeration rate and frother will have almost the same effect on the bubble sizes. But its effect on the degree of sphericity of the bubbles will be higher.

4. NEURAL NETWORKS MODELING

In recent years, neural networks are widely recognized and attracted particular interests for its ability to interpret pattern based information and ill-posed problems. In this work a feed forward network with a hidden layer have been employed by adopting Zigmoid transfer function (tangent hyperbolic). Furthermore, in order to assess the results, two different architectures have been considered for modeling and their outcomes have compared.

Case 1 A 6:4:1 architecture for input-output pattern has been considered. Input will include color and surface froth structure which embodies mean bubble size, bubble size distribution, bubble circularity factor, mean color and its distribution where the output can be either the grade or the mass flow rate (Figure 5a).

Case 2 A 6:5:2 architecture for input-output pattern have been adopted. In this case, the output cell performance parameters can also incorporates the grade and the mass flow rate of the solid (Figure 5b). In order to train the networks, about 70 percent of input-output data was selected in a random manner and the rest of the data were used to test and validate the outcome and assess the errors resulted from it. Moreover, it is usually advantageous to predict the network outcome by adopting linear regression between the network output and the target and hence estimating the coefficient of correlation for it. Therefore, it was possible to explain the deviation of the network outcome from the target. If this coefficient is one, it indicates a good fitness and low noise between the data sets. Figures 6 to 9 exhibit the extent of the susceptibility of the nets in map learning from the input-output patterns of the two above cases. From these figures, coefficient correlations of 0.95 and higher were obtained which shows an acceptable fitness through an appropriate training and test of the nets. However, the coefficient correlation that is obtained from the linear regression modeling was about 0.54, which exhibits its inadequacy as compared to the nets. It is also evident from the results obtained from the above two cases that with a simple alteration in the architecture of the nets; we can increase the flexibility and the extent of the susceptibility of the solution of a complicated and ill-posed problems. Therefore, it is possible to adopt nets for modeling for similar cases with a high degree of precision.

5. CONCLUSION

The results obtained from the image analysis technique and cell concentration flow, reveals that there exist a coherent relationship between froth characteristics and cell performance. The research also exhibit that froth with small bubble has lower solid mass flow rate in contrast to a larger one. It was also concluded that froth color could be assessed by component of hue color histogram. In addition, it shows that a high-grade froth exhibits a sharper hue color histogram. The results obtained from nets modeling demonstrate that a feed forward net with a hidden layer can enable us to predict cell performance from froth characteristics with high degree of precision. Therefore, a combination of image analysis techniques and nets can be applied as a powerful tool to analyze and control the performance of a flotation cell.

6. ACKNOWLEDGMENT

We gratefully acknowledge the support and help of the department of Research and Development of Sarcheshmeh Copper Plants for this research, in particular Mrs. A. Partoazar, Mr. H. Rezayan, Mr. H. Javani, Mrs. Zeidabady and Mr. H. Shahrahmani.

7. REFERENCES

1. Moolman, D. W., Aldrich, C., Van Deventer, J. S. J. and Stange, W., “Digital Image Processing as Tool for On-Line Monitoring of Froth in Flotation Plants”***, Minerals Eng.,*** Vol. 7, No. 9, (1994), 1149-1164.
2. Van Deventer, J. S. J., Bezuidenhout, M. and Moolman, D. W., “On-Line Visualization Flotation Performance Using Neural Computer Vision of the Froth Texture”***, Min. Cong.,*** Aachen, Germany, (1997), 315-326.
3. Bonifazi, G., Serranti, S., Volpe, F. and Zuco, R., “Characterization of Flotation Froth Color and Structure by Machine Vision”***, Computers and Geosciences,*** in press, (2000).
4. Bonifazi, G., et. al., “Characterization of the Flotation Froth Structure and Color by Machine Vision (CHACO)”***, Proc. XXI Int. Min. Proc. Cong.,*** (2001), C8a-39-C8a49.
5. Castleman, Kenneth R. “Digital Image Processing”, McGraw-Hill Book Company, N. Y., (1996).
6. Bonifazi, G., Massascci, P. and Meloni, A., “3D Froth Modeling by Image Analysis”, ***Proc. XXI Int. Min. Proc. Cong.***, (2001), B8a-178-B8a189.
7. Saghatoleslami, N., Karimi, H., Rahimi, R. and Shirazi, H. A., “Quantitative Experimental Investigation of the Effect of Operating Conditions on the Froth Structure in Copper Flotation Process, using Image Analysis”, ***Iranian J. of Chemistry and Chemical Eng.***, In press, (2004).
8. Moolman, D. W., Ekesteen, J. J., Aldrich, C. and Van Deventer, J. S. J., “The Significance of Flotation Froth Appearnce for Machine Vision Control”***, Int. J. Miner. Process***, Vol. 48, (1996), 135-158.