



Digitalization in Mining and Mineral Processing – a New Solution for Potential Increasing the Metals Recovery

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Abstract

The paper deals with issues of increasing the recovery of useful copper minerals through the application of specific production scheme. A new model of production presented in the paper is connected with technology for monitoring and control of copper ore processing and is based on artificial intelligence. The technology operates at the copper flotation stage and consists of a vision system for analysis of flotation froth images. Image processing algorithms determine the characteristics of the froth and on that basis are capable of modifying and optimizing the flotation process course. The article characterizes the concept and expected outcomes resulting from the implementation of this technique.

Keywords: mineral processing, optimization, image analysis, flotation

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1. INTRODUCTION

The technology of raw materials beneficiation is relatively simple in its idea, because its main purpose is to separate a useful mineral from a gangue with the highest possible and economically viable effectiveness. The problem becomes significant in terms of ores, especially for the run-of-mine with complex mineralization of useful compounds. A proper recognition of the feed material becomes a key-point in selection of specific processing technology for a given type of feed. Obtaining a specific information within this area can be utilized in a number of activities and research aiming at optimization of technological circuits of raw materials (Numbi and Xia 2015, Saramak et al. 2010, Saramak 2021). These improvements, in turn, should aim at increasing the effectiveness of mineral processing plants, that can be achieved through increasing in recovery of useful components in concentrate (Erskine et. al 2024, Lin and Miller, 2010) lowering operational cost (Nadolsky et. al 2013) or reduction the raw material loss in waste and environmental impact (Arrowsmith and Ashton 1991, Saramak et. al 2016).

Contemporary analytical methods more commonly utilize computer-based techniques for qualitative and quantitative assessment of a raw material. Image analyses and video techniques supported by the microscopy, for example, help in determination of physical properties of individual particles, like the shape and size (Abbireddy and Clayton 2009, Cavarretta 2009, Nad and Saramak 2018, Janaszek 2024). Even if technological development and automation of measurements allow for increasing the representative number of particles in the measurement, the methods based on microscopy generally include 2D image analysis. More advanced technology utilizes 3D scanning, 3D optical microscopy, computed to-

mography and dynamic image analysis methods, for a more detailed description of individual particles. They are usually capable of overcoming the problem of measurement and recording a large number of images in short periods in a way that it is statistically representative (Fonseca 2011, Schmitt et al. 2016).

Other advanced methods of quantitative image analysis based, for example, on Fourier descriptors (Bowman et al. 2002, Sukumaran and Ashmawy 2001) can be also applied. However, they can be useful only in basic and rather simple investigations because a degree of complexity limits their practical application to the particle shape characteristics. To upgrade this approach, a methodology that identifies the particle morphology should be used, which can generate relevant and easily interpretable descriptive parameters (i.e. convexity, circularity).

Images of individual particles may bring information not only on the particle's size and shape, and other physical properties of the material, and may characterize the course of crushing and grinding operations. Such information may be used as feedback for the process control and optimization, when, for example, a product with specific characteristics is expected to be obtained. In the case of separation operations, images of flotation froth may be used in collecting information on flotation process characteristics. and course. Such visual information is difficult to obtain, but specific visual systems are being implemented in the plant conditions, like the FloVis system installed in KGHM, FrothSense+, created by Metso Outotec and VisioFroth (Konieczny et al. 2011). They can capture images of the froth from a flotation machine and then they process it and calculate specific froth parameters like size, shape, and color of bubbles and their mobility. They are used further to control the parameters of the flotation process.

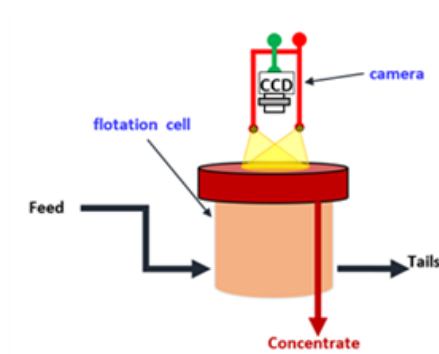


Fig. 1. Placement of the vision system
Rys. 1. Umiejscowienie systemu wizyjnego

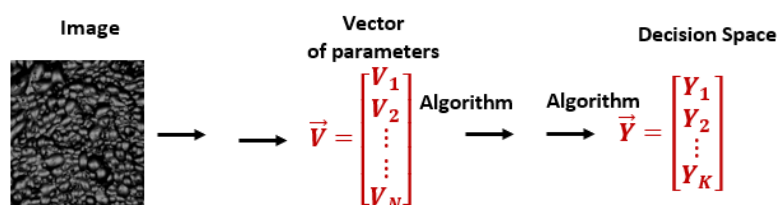


Fig. 2. Scheme of vision system
Rys. 2. Schemat układu wizyjnego

Even though such systems help in flotation process control and are justified from the economic point of view, the image parameters are not closely linked to the froth characteristics, and knowledge about this relation could have a great effect on improvement of effectiveness of flotation process course and could improve the overall economy of a processing plant. There are two main approaches toward analyzing the images of the froth in the flotation process. In the first one, the information is extracted directly from the froth image (Abbaker and Aslan 2024, Konieczny et al. 2011) through the bubble size, shape, velocity etc. The second approach is based on the Fourier transform of the froth image (Sztaba and Lenczowski 1993, Lenczowski et al. 1993). The image parameters, called the descriptors, are linked to the froth parameters, i.e., bubble size, shape, velocity, but these connections are neither straightforward nor intuitive. These parameters should be treated as statistical image descriptors and are very useful in statistical image recognition processes.

The machine learning process (ML) provides the ability to determine the relationship between the froth characteristics and the froth image parameters. It is based on the training groups of froth images, registered in various stages of the flotation process. The ML process leads to the Image Recognition (IR) algorithm, which enables establishing a relationship between the froth image and froth characteristics, understood as useful mineral content (Korder and Lenczowski 1988, Galas et al. 1994, Galas 1994). To perform that, however, the Image Analysis procedure must be sensitive enough to detect significant variation in the flotation process parameters. Interesting applications of IR algorithms in the flotation technology can be found in the literature (Galas et al. 1994, Lenczowski and Galas 1995, Lenczowski and Galas 1998).

2. MATERIALS AND METHODS

The leading idea presented in this paper consists in showing potential benefits of ore beneficiation in flotation oper-

ations. Application of vision systems to control the flotation process course is becoming more popular. Specific sensors of image transformation measure selected parameters of flotation froth and on that basis the system can modify the operational parameters of the process. The flotation process will be carried out for sulphide copper ores and the entire flotation consists of several operations including rougher, main and cleaning flotation. The CCD camera observes the surface of the flotation froth in selected flotation machine (Fig. 1). The image is transferred from the CCD camera placed in the optical measurement point (OMP) to the computer for further processing and analysis. The idea of methodology can be characterized as follows:

- The vision system captures images of the flotation froth through a collection of cameras placed above the surface of the flotation machine;
- Froth image processing algorithms determine the values of parameters characterizing the flotation froth. The parameters characterize structure, variability, flow rate and transparency of the froth, as well as the share of individual colors in the RGB and HSV space.
- The flotation process steering parameters are modified according to the obtained values of the visual parameters.

The computer used in the experiments was a standard commercial PC working under Windows. It was equipped with the digital CCD camera, 512 x 512 pixels, 1 byte/pixel and 20 GB HDD for data. Authors of this paper have developed the specialized software for image acquisition and processing. The Linear Discriminant Analysis was used for correlation images with a Pb content in the flotation froth. The Discriminant Functions applied to calculated image features enabled us to classify a given image to a training group of images that represented the froth images of similar value of a Pb

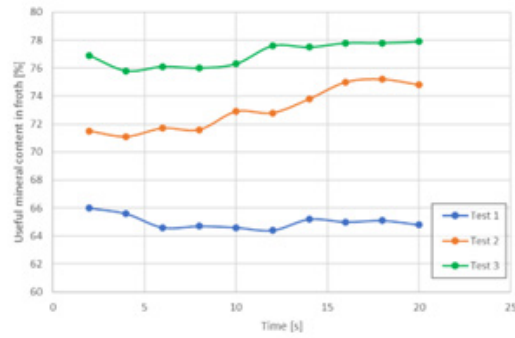


Fig. 3. Test results
Rys. 3. Wyniki testów

Tab. 1. Results of experiments
Tab. 1. Wyniki eksperymentów

	Test 1	Test 2	Test 3
Average Pb content	65.00	73.04	76.79
St. deviation	0.47	1.49	0.80
Range	1.6	4.1	2.1

Tab. 2. Recognition of images from individual groups
Tab. 2. Rozpoznawanie obrazów z poszczególnych grup

	Group 1	Group 2	Group 3
Group 1	60.0%	29.8%	10.2%
Group 2	25.9%	74.1%	0.0%
Group 3	1.5%	24.9%	73.6%

content in the froth. The Pb content in the froth was measured in the chemical way.

The calibration procedure of the system requires a parallel sampling of flotation froth for XRF and chemical analysis for determination of the useful mineral content in the froth. Once the image of the individual picture is linked to technological results (i.e. content of useful minerals in the froth) the training process of the system can be carried out. Training of recognition and classification algorithms requires application of linear discriminant analysis (LDA) and an artificial neural network (ANN). In these systems, a single image is described by a set of parameters or by its pixels. It is based on a set of M-groups of training images that characterize various types of flotation froth, which can be associated with different course of technological process of beneficiation. The scheme of LDA is presented in Fig. 2.

This procedure treats a single image as a point in k-dimensional decision space. Images are categorized into several groups according to the useful mineral or metal content. The group centroid, understood as its gravity center, is determined for each group. A specific image is classified into an individual group according to the classification (or recognition) rule, which takes into consideration the distance to the group centroids. The image is classified to the group for which a distance to the gravity center (a group centroid) is minimal among all the groups in question. The procedure for ANN algorithm is similar, but a Decision Vector (instead of Decision Space) is obtained as a result of recognition. Each coordinate of this vector indicates a specific group, to which image is assigned. The image is classified into a specific group when the coordinate of the vector equals 1. Then we obtain a vector of m-length (where m denotes a number of groups), with one value of 1 and the remaining values of 0.

3. RESULTS OF INVESTIGATIONS

Figure 3 summarizes the results of each test. It can be seen that for test 1 rather lower values of Pb content in the froth were registered. Variation of these results seems the lowest, as well. Test 2 presents average Pb contents, while the highest values of the useful mineral were registered during test no. 3. Table 1 characterizes average Pb values for each test, along with determination of standard deviations and ranges of variability.

On the basis of the presented results it can be seen that various average contents of Pb were obtained for each test. If, additionally, we take into account that each test was carried out for different operational conditions, we can see, that the setting of these conditions can be associated with average content of mineral in the product, and thus, operational regime directly affects the quality of the flotational products.

Another interesting issue is that variability of Pb content is different for each test, and its changeability may be, to some extent, connected to the level of Pb content in the froth. For example, for low Pb content, the standard deviation is low and equals 0.47 percent. Together with increasing of the average Pb content (test 2), the standard deviation increases either, but further increase in Pb content decreases the standard deviation. Therefore, it is possible to conclude, that the relationship between variability of useful mineral content in flotation product and quality of flotation product, measured through the average content of Pb, can be described through a parabolic function. It should to be pointed out that it is not a firm state, and such relationship should be verified through more detailed investigation, prior to acceptance.

Table 2. summarizes the results obtained during image recognition and classification into specific groups. For the purposes of this article it was assumed that three groups of

images, reflecting three levels of Pb content, were registered. It can be seen from the Table how many images (in percentages) were assigned to individual groups. For example, for test no. 1, 60% of images were assigned to group 1, 29.8% to group 2 and 10.2% to group 3. The results should be interpreted in rows, not columns.

4. DISCUSSION AND SUMMARY

The results of experiments presented in the paper show that it is possible to link the characteristics of flotation froth with the quality of individual beneficiation products. The results also showed that the characteristics of froth for individual tests are different and each test was carried out at different operational conditions. Thus, the results obtained through the vision system can be correlated with the process course and, as a result, it can be possible to control the content of the useful mineral in the product through the control of machine work.

It was also shown that implemented algorithms worked efficiently and were able to adjust the process of image recognition. It should be noted, however, that the process of machine learning is more efficient to conduct for stable conditions of Pb contents and low variations. Operational and technological practice show that this is a complex process and maintaining very stable conditions of beneficiation process is not easy. Therefore, the relationships presented in the paper should be verified during further investigations.

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Digitalizacja w górnictwie i przetwórstwie mineralów – nowe rozwiązanie dla potencjalnego zwiększenia odzysku metali

W artykule podjęto problematykę zwiększenia odzysku użytecznych mineralów miedzi poprzez zastosowanie określonego schematu produkcji. Przedstawiony w artykule nowy model produkcji jest powiązany z technologią monitorowania i kontroli przeróbki rudy miedzi i opiera się na sztucznej inteligencji. Technologia ta działa na etapie flotacji miedzi i składa się z systemu wizyjnego do analizy obrazów piany flotacyjnej. Algorytmy przetwarzania obrazu określają charakterystykę piany i na tej podstawie są w stanie modyfikować i optymalizować przebieg procesu flotacji. W artykule scharakteryzowano koncepcję i oczekiwane rezultaty wynikające z wdrożenia tej techniki.

Słowa kluczowe: *przetwarzanie mineralów, optymalizacja, analiza obrazu, flotacja*