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ScienceDirect
Trans. Nonferrous Met. Soc. China 24(2014) 2665−2676
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Rapid vision-based system for secondary copper content estimation

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Received 8 July 2013; accepted 30 September 2013

Abstract: A vision-based color analysis system was developed for rapid estimation of copper content in the secondary copper smelting process. Firstly, cross section images of secondary copper samples were captured by the designed vision system. After the preprocessing and segmenting procedures, the images were selected according to their grayscale standard deviations of pixels and percentages of edge pixels in the luminance component. The selected images were then used to extract the information of the improved color vector angles, from which the copper content estimation model was developed based on the least squares support vector regression (LSSVR) method. For comparison, three additional LSSVR models, namely, only with sample selection, only with improved color vector angle, without sample selection or improved color vector angle, were developed. In addition, two exponential models, namely, with sample selection, without sample selection, were developed. Experimental results indicate that the proposed method is more effective for improving the copper content estimation accuracy, particularly when the sample size is small.
Key words: secondary copper; copper content estimation; sample selection; color vector angle; least squares support vector regression

1 Introduction

Copper recovery from wastes is more economically appealing than copper production from primary sources [1]. Reusing waste copper not only reduces the cost of production, but also saves the natural resources and energy of the earth from a big stand of view. Therefore, the interest in copper recycling technologies has been steadily increasing in recent years [2−8]. The final product of copper recovery process is usually called secondary copper in smelting industry. However, measuring the content of the secondary copper mainly relies on the expensive spectrograph through an off-line manner, which may introduce a significant measurement delay. In this delayed period, the melting process will not stop keeping the molten copper at a specified temperature range until the desired measurement result of copper content is reported. Therefore, much energy is wasted in this period. In addition, spectrograph machines may not work well in a dusty on-site condition with high temperature, which may introduce extra difficulties for measuring copper content. Overall, much fuel and energy have been wasted in traditional spectrograph approach. To overcome these problems, a rapid copper content measurement system is highly desired.

Like other quality monitoring problems [9], a key step of constructing an in-situ copper content measurement system is to select fast, reliable, and low-cost sensors. With the development of digital image acquisition and processing methods, vision-based techniques have become more and more popular [10−14]. The idea of implementing rapid secondary copper content measurement using the vision-based system is innovated for several reasons. Firstly, The vision-based system has been successfully adopted for copper quality estimation [15], as well as in other industrial applications [16−18]. Secondly, the copper content prediction at the smelting location (in-situ) is usually estimated by skilled workers based on their accumulated experiences. The human experts make judgments on the copper product contents with their direct visual observations. Therefore, it is possible to use a vision system to estimate the copper content.

Foundation item: Project (2011BAE23B05) supported by National Key Technology R&D Program of China; Project (61004134) supported by the National Natural Science Foundation of China; Project (LQ13F030007) supported by Zhejiang Provincial Natural Science Foundation of China
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DOI: 10.1016/S1003-6326(14)63397-5

Previously, OESTREICH et al [12] demonstrated the use of color features for real-time mineral quality estimation. Recently, color features have been used in quality evaluation for fruits [10] , beef [19] and other foods. KIM et al [15] suggested that the hue intensity may reflect the composition difference of Zn, Sn or Al in the Cu binary alloys. An exponential equation model was used for composition estimation of Cu−Zn, Cu−Sn and Cu−Al alloys by measuring the average hue intensity. However, defects on the surface of a copper sample may affect the average values of hue intensity, which may result in a significant error of the quality estimation model. Therefore, a sample selection strategy by defect detection can be used to improve the accuracy of the estimation model. Besides, since the composition of secondary copper is more complex than ideal Cu binary alloys, the exponential equation model may not function well to model the relationship between color feature and copper content of secondary copper.

In the present work, we develop a copper content estimation model based on color analysis, where the development of the copper content estimation model is treated as a supervised regression problem. Firstly, mean filtering is employed to remove noise and the region of interest (ROI) method is applied to segmenting copper images from the background. Secondly, the Canny edge detection technique is combined with luminance standard deviation for detecting the defects and selecting appropriate modeling sample images, followed by the extraction of improved color vector angle. Finally, a LSSVR model is developed to correlate the copper contents and the extracted color vector angles.

2 Vision-based system

The proposed vision-based system consists of two main parts: the hardware and the software. The hardware is an image acquisition system, which captures images of copper samples in the smelting process and transmits the images to the computer. The software is specially developed to analyze the captured copper images and estimate the copper content of the testing secondary copper samples. The vision-based copper content estimation system has been established both in the lab and in-situ. The major tasks performed by the system are shown in Fig. 1, which are copper image acquisition, defect detection, color feature extraction and copper content estimation.

2.1 System hardware

The image acquisition system consists of a color assessment cabinet with D65 light sources, a 3CCD color camera and an industrial computer. The cabinet is applied to keeping dust away and providing a constant lighting condition. D65 (PHILIPS TLD 18W/965) is a kind of artificial daylights acknowledged by CIE, whose color temperature is 6500 K. An industrial 3CCD progressive scan RGB color camera (JAI, model CV-M9GE 3×1/3″, 1024×768 active pixels) mounted with a 15 mm lens (FUJINON, model TF15DA-8) is applied to capturing the images of secondary copper samples. The copper images are transmitted from the camera to the industrial computer through Gigabit Ethernet. Compared with a traditional single CCD color camera, the 3CCD color camera is more precise and reliable, which could capture more accurate color information from the secondary copper samples. In addition, the copper samples are fixed by a sample holder to ensure that every image has the same shooting angle and the illumination angle shown in Fig. 2. Especially, the shooting angle is adjusted to reduce the effects of reflection and ensure that the image defect is not derived from the illumination. The photograph details of the proposed vision system are presented in Fig. 2.

2.2 System software

The developed software consists of two main parts: a user interactive interface and a copper content estimation program. The user interface is written by

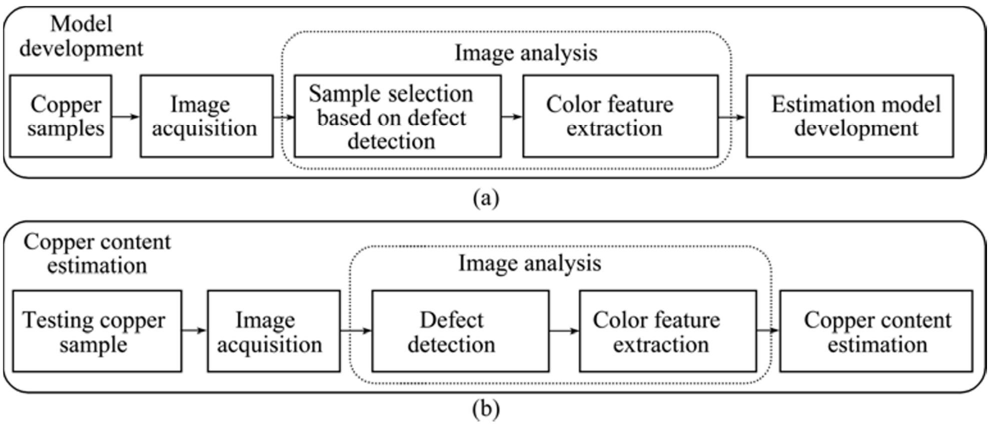

Fig. 1 Schematic diagram of copper content estimation system: (a) Model development; (b) Copper content estimation