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CLASSIFICATION OF STEEL SCRAP IN THE EAF PROCESS USING IMAGE ANALYSIS METHODS

KLASYFIKACJA ZŁOMU STALOWEGO W PROCESIE EAF Z UŻYCIEM METOD ANALIZY OBRAZU

Industrial practice and market situation shows that there is still a big degree of uncertainty when it comes to scrap material properties in EAF process. Fast development of machine vision technology and software allow to challenge with this problem. The main goal of this work is to extract the most information for the process of loading scrap into the charging baskets. Data concerning transferred scrap are acquired from digital industrial camera and processed by the mean of image analysis methods. There are certain image features, which allow to describe the scrap for the classification. The extracted features will be used to build the machine vision system for steel scrap classification. Research on the intelligent control of the electric-arc steelmaking process is done by the authors within the research project[1])

Keywords: electric arc furnace, image analysis, steel scrap, feature extraction, knowledge extraction, pattern recognition, image stabilization

Praktyka przemysłowa oraz sytuacja na rynku pokazują, że nadal jest duży stopień niepewności, jeżeli chodzi o własności złomu w procesie EAF. Szybki rozwój technologii urządzeń wizyjnych i oprogramowania pozwala na sprostanie tym problemom. Głównym celem tej pracy jest największe wydobycie informacji na temat jakości złomu ładowanego do koszów załadowczych. Dane dotyczące transportowanego złomu są uzyskane cyfrowej kamery przemysłowej i są przetwarzane metodami analizy obrazu. Zdjęcie ma pewne cechy, które pozwalają na klasyfikacje złomu. Własności te będą użyte do zbudowania systemu klasyfikacji złomu stalowego. Badania nad inteligentnym sterowaniem procesem wytapiania w piecu łukowym są wykonane przez autorów w projekcie badań.

1. Introduction

Steel scrap is used in steel production in the electric-arc furnace. Because of the costs the most frequently used type of scrap is so called merchant scrap, which consist of a variety of elements [1]. Industrial practice and market situation shows that there is still a big degree of uncertainty when it comes to determine scrap material properties. Assigning of the scrap to a certain class is very important, because of the need of the demanded charge structure, which provides best melting conditions and the electric arc furnace indefectibility [2].

2. Steel Scrap classification system

Machine Vision Systems are used for more and more complex objectives, because of the fast growing technology and software. This development together with computational intelligence techniques allow to solve the problem of the scrap metal classification. The goal is to acquire as much data as possible from the process of loading the charging baskets with metal scrap in the EAF process. Information about the scrap is gathered during the processing steel scrap images taken by digital machine vision cameras. The final goal (for which this data is gathered) is to build machine vision system for automatic steel scrap classification. At the present stage of development, the system is used to collect a data set which will allow to find the best classification model.

The system will track charging baskets and electromagnets on every camera frame. Among all the captured frames only these ones will be analyzed, where an electromagnet is positioned right over charging basket (just before dropping metal scrap). Scrap metal will be extracted from the rest of the image using background estimation algorithm. The system will be working in extreme conditions, that is why it is so important to consid-

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er all environmental factors during the initial stage of the project. The most important factors are changing light conditions, different temperatures and changing distance between inspected objects and cameras. This requires thorough image preprocessing in order to extract objects for analysis from the images and calculate the size of objects. Although cameras are supposed to be mounted inside the cases which are shock absorbent, it is still necessary to implement software image stabilization. To classify steel scrap it is essential to extract from the images as much information as possible. That is why it is necessary to use many image analysis algorithms and adapt them to the given task. The applied algorithms are: edge detection, binary large objects analysis, image segmentation and gauging.

Loading the charging baskets process is carried out not in one place but in the whole steelwork building. That is the reason why the system will have to use at least two cameras to cover all the loading area. The system will be based on the GigE Vision technology, where the Gigabit Ethernet network interface and equipment are used to send image frames from camera to computer system. The deployment of this interface is the best solution for large industrial facilities, because the distance between the camera and computer could be even 100 meters long. In the same time this solution is very economical, because it eliminates the use of frame grabber. Another advantage would be the use of existing network infrastructure in the steelwork providing it is working in Gigabit standard.

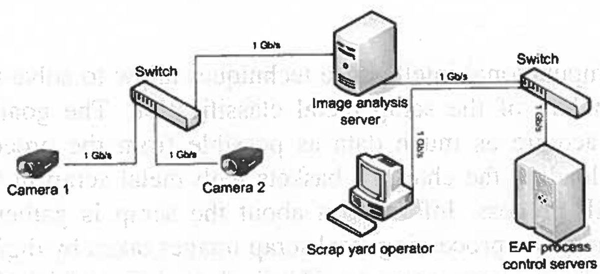

Fig. 1. Steel scrap classification system

The best performance and precision of Machine Vision System depends on the environment where it will function. It's important to design the system which is the most suitable for the process environment [3]. In most cases when deploying such system the process environment is changing in aspects such as lighting or temperature. When it comes to the steel scrap classification system these changes are in fact not possible, because of the construction and size of the building. That is why it was so important to make a precise analysis of environment, system requirements, and hardware capabilities. There are certain parameters which are already determined for the realization of this project. Basic condition is the camera sensor resolution. High resolution is inevitable to acquire images with a sufficient number of details to classify steel scrap precisely. Sensors which meet this requirement should have at least 2 megapixels resolution. Second condition is the sensor sensibility, which will allow to work in different light conditions. Third requirement that the camera should meet would be the color because hue of the scrap is sometimes crucial for the classification. The last condition is to use camera which is designed for harsh environment, due to low temperature, shocks and dust that occur in the process environment.

3. Image preprocessing

Image analysis is meaningful when the objects for the analysis are recognized and located in the image. In the steel scrap classification system, an image preprocessing phase is complex because of diverse background and different scale of the objects. First stage is to locate charging basket and electromagnet with the use of pattern matching algorithms. The outcome of these algorithms indicate the position and scale of the found objects.

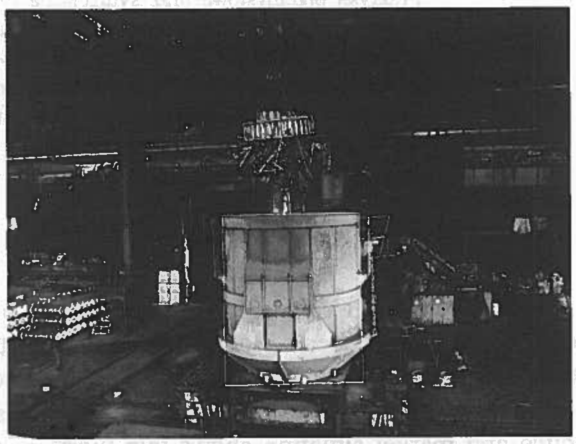

Fig. 2. Finding objects: charging basket, electromagnet with scrap

With the real size of the charging basket and electromagnet, it is possible to transform a pixel coordinate to a real-world coordinate. This allows to measure objects regardless their distance from the camera. Measuring basket and electromagnet helps to determine the mutual position. Because of the camera field view calibration it is possible to position the objects in three dimensions. Positioning is done because only those images where electromagnet is right above the basket (just before dropping scrap) are qualified for analysis. Other images are used for tracking objects and registering the moments of dropping the scrap. These selected frames are not ready for analysis yet. The next phase of preprocessing is to separate scrap from the surrounding background. However it is not possible without image stabilization algorithm, which compares two images: one which is used for analysis and one which was taken some seconds before. Two areas which are always the same (for example some part of building construction) are located on the pictures by geometry matching algorithm. One of them must be moved and rotated to match the areas position on the other picture [4]. Those two images are also used for the background estimation, where they are compared and only those pixels which colour value differs to certain degree, have value represented by white colour on resultant binary image.

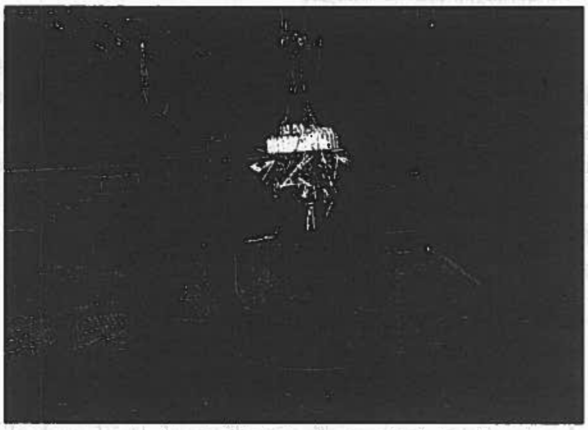

Fig. 3. Image after background estimation algorithm

Binary image is further used with a few morphological operations to filter out noise and join contiguous steel scrap objects. Noise is removed by small objects removal algorithm. closing and dilatation operations are used to group the scrap objects. To analyze the structure of transported scrap is necessary to multiply resultant binary image with the original image to obtain the extracted steel scrap image.

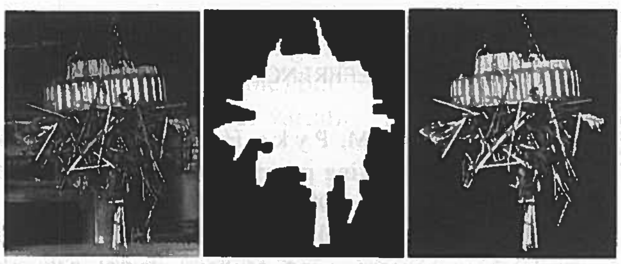

Fig. 4. Steel strap image extraction: a) original image, b) extracted binary image c) resultant image

4. Volume assessment

With the extracted steel scrap image it is possible to analyze certain scrap features. From the practical point of view the volume of the steel scrap which is transported on the electromagnet is very important. The weight of the steel scrap measured with the scale mounted on the electromagnet, when divided by the volume, equals the density. It is one of the main parameter used in assigning the class of scrap. This was the reason for implementing scrap volume assessment algorithm, which will give the density of scrap when combined with the values from the scale.

The assessment algorithm divides the whole pile of scrap into segments. Every segment is treated as a cylinder the diameter of which equals the length of a dividing line. The height value is the distance between segments. When the shape is concaved and the dividing line crosses its edges more than twice, the vectors are treated as different cylinders with diameter equal the distance between edges.

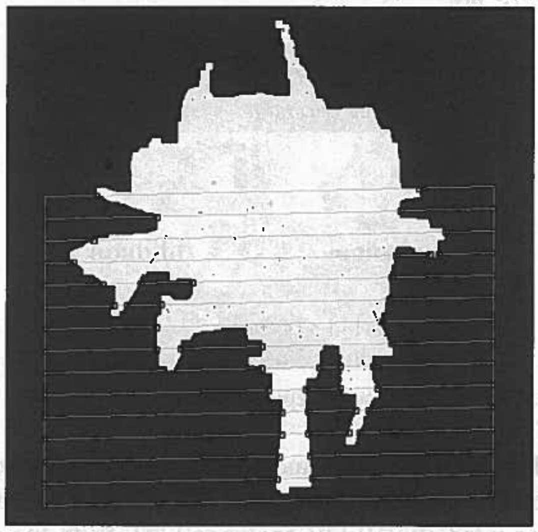

Fig. 5. Analyzed object divided into segments

Each cylinder volume must be added to calculate the overall volume of the scrap (1). Larger number of segments will give better assessment of the volume.

$$V_S = \sum_{i=1}^{n} \sum_{j=1}^{\frac{k_i}{2}} \pi(\frac{d_j}{2})^2 h \qquad (1)$$

where: V_S – volume of scrap, n – number of segments, k_i– number of crosses on i segment line, d_j – length of vector j on $i$segment line, h – distance between the segments.

It is assumed that if the electromagnet is round, the scrap which is carried will come together in a similar shape. This simplification might be unreliable in many cases, but seems to be a reasonable solution when analyzing two dimensional image taken by a single camera.

5. Feature extraction

Steel scrap is divided into separate classes not only by its density, but also its origin, chemical composition and structure. The goal is to discover how such features are related to the image features. That is the reason why it is so important to use as many image analysis algorithms as possible. To extract all the feature it is crucial to analyze only the steel scrap. Extracted image (by background estimation algorithm) contain steel scrap and the electromagnet, which should be removed. The exclusion of the electromagnet is possible, because the position and the size of the electromagnet are already known from object positioning.

Colour features are very intuitive, so from the image are extracted parameters which indicates mean values and standard deviation of colours. These image features allow to recognize if the scrap is rusted and homogeneous or not.

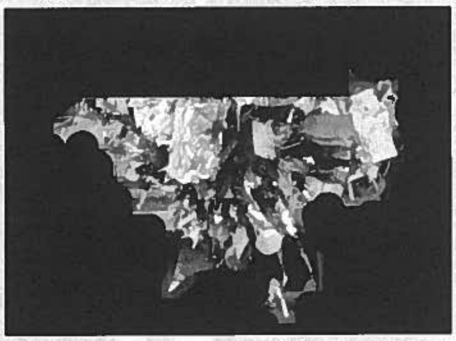

Fig. 6. Extracted steel scrap region

The physical sizes and fragmentation are described by object detection algorithm, which locates objects with similar intensity (BLOB analysis[2)]) [5]. With the use of this algorithm every scrap image is described by some values which indicate a number of objects and also maximum, minimum and mean size of them.

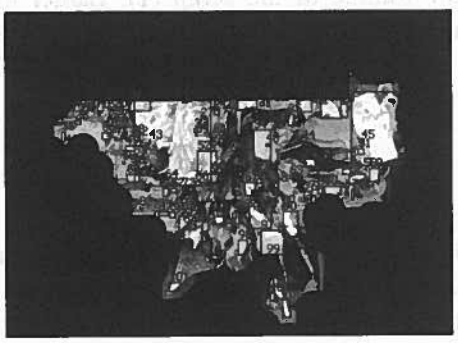

Fig. 7. Detected objects in steel scrap region

Many important information is extracted only from the shape of steel scrap region. Such parameters as compactness, circularity and contour length can indicate what class of scrap is registered at the analyzed image.

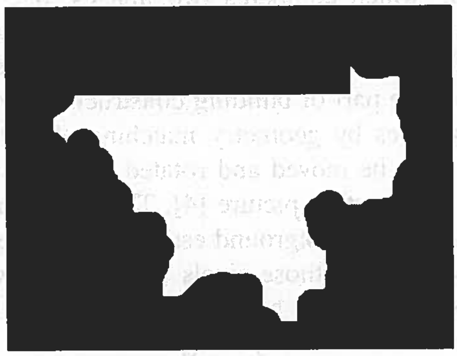

Fig. 8. Steel scrap region analysis

All those features, extracted from analyzed images will create the data set, which will allow to find the best classification model, with the use of data mining tools and methods. Besides those already implemented image analysis algorithms, there will be additional ones, which will help to enhance accuracy of steel scrap classification.

6. Summary

In the EAF process the quality of steel and effectiveness of the process depends on many factors, but one of the most significant is a proper steel scrap configuration in charging baskets. Because of the large amount of transported scrap and very often unreliable steel scrap classification carried out by steel scrap merchants, it is crucial to classify scrap during the process of loading charging baskets. For this reason, the system which extracts scrap features from the images, and automatically classifies steel scrap according to those features, was designed.

REFERENCES

[1] T. W i e c z o r e k, M. P y k a, Hybrid expert system for arc-electric steelmaking process monitoring. Acta Metallurgica Slovaca **10**, 408-412 (2004).

[2] T. W i e c z o r e k, Intelligent control of the electric-arc steelmaking process using artificial neural networks. Comp. Methods in Material Science, 6, 1, 9-14 (2006).

[3] F. T r d i c, Proceedings of the Real-time Machine Vision in Mineral Wool Production, Industrial Vision Days, Stuttgart 2006.

[4] C. D e m a n t, B. S t r e i c h e r-A b e l, P. W a s z k e w i t z, Industrial Image Processing: Visual Quality Control in Manufacturing, Springer-Verlag, 1999.

2) BLOB analysis – Binary Large Object analysis

[5] C. S t e g e r, M. U l r i c h, C. W i e d e m a n n, Machine Vision Algorithms and Applications, Wiley-VCH, Berlin, 2007.

[6] M. E. J. W o o d, N. W. C a m p b e l l, B. T. T h o m a s, Employing region features for searching an image database. In Proceedings of the British Machine Vision Conference, 1997.

[7] E. W i l s o n, M. K a n, A. M i r l e, Intelligent Technologies for Electric Arc Furnace Optimization. Proc. of Electric Furnace Conference, New Orleans, Louisiana, 1998.

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