

Classification of Segregation Level in Steel Wires by Image Processing

Karel Horak

Abstract—This article describes a visual measurement system intended for an automatic determination of segregation level in steel wires. The suggested system is principally based on image processing methods for segmentation and classification of inhomogeneous regions inside an otherwise uniform wire. Until our automated inspection system has been deployed, the measurement of segregation level was performed by an inexact and subjective evaluation by a human inspector. The visual measuring system involves an image acquisition stage, image pre-processing, wires segmentation and finally wires classification. In the following text all these parts of evaluation process are described in-depth. Finally each wire is automatically classified into the one of several predefined classes by the mentioned sequence of image processing steps.

Keywords—Image processing, Classification, Statistical Segmentation, Segregation Level, Steel wires.

I. INTRODUCTION

VISUAL inspection and measuring systems are more and more popular as the time goes because of their non-destructive character [1]–[4]. A visual inspection of steel wires, which is described in this paper, is the only one example of such systems.

A. Task Definition

In general, a definition of the task is simple: to evaluate a level of a material segregation in steel wire submitted for the inspection. At the beginning a manufacturer produces steel wires in form of a long rods surrounded by a hard plastic.



Fig. 1. Examples of the six-wired and the twelve-wired cylinders.

A small piece of such cable is cut off for an inspection from time to time. This piece of the cable is called cylinder and several examples are shown in the Fig. 1.

Manuscript received February 18, 2014. This work was significantly supported by the project Centre for Applied Cybernetics 3 No. TE01020197 under the Technology Agency of the Czech Republic and also by the grant Research of New Control Methods No. FEKT-S-14-2429 from the Internal Grant Agency of the Brno University of Technology.

K. Horak is with the Department of Control and Instrumentation, Brno University of Technology, Brno, 61600, Czech Republic (phone: 00420-5-4114-6417; fax: 00420-5-4114-6451; e-mail: horak@feec.vutbr.cz).

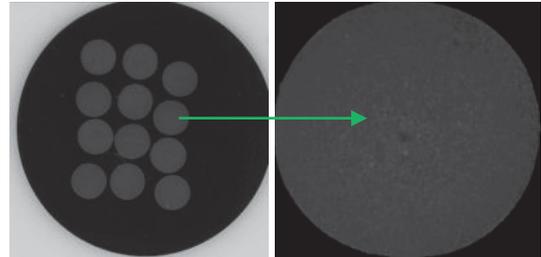


Fig. 2. A cylinder with twelve wires and a material segregation inside a wire.

A number of wires inside a certain cylinder can vary from three up to twelve, however the most often constellation is the cylinder with the six or twelve wires. Regardless of the number of wires in the cylinder, each individual wire is examined and the level of the material segregation is determined. All wires are made from the steel, so it means they are compounded from an iron, carbon and other less chemical elements. Just the carbon and other ingredients are responsible for formation of the inhomogeneity regions inside the wire during solidification. These regions can be observed as small dark dots in a centre of the wire as it is depicted in the previous Fig. 2.

B. Solution Framework

The most significant problem of the autonomous visual inspection of the steel wires is about accuracy and repeatability, because of the material segregation is very often imperceptible and hardly noticeable in an image. Moreover there exist several types and levels of the material segregation in the industrial standard sheet which is shown in the Fig. 3. On the basis of this standard each wire has to be then classified into the one of the pre-specified classes for example as the UL-B.

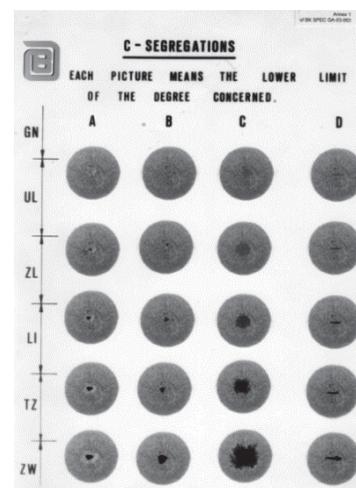


Fig. 3. The standard sheet of patterns for classification of the segregations.

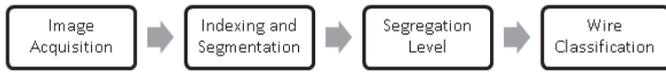


Fig. 4. Visual inspection: a sequence of an image processing steps.

The end-user application *Segregation Analyser* was designed and image processing algorithms were implemented for a purpose of the mentioned autonomous inspection. A sequence of these algorithms is depicted by means of the scheme in the Fig. 4.

The first step of an image acquisition is performed by means of an ordinary office scanner which is controlled directly from the application via its driver. Such way of image acquisition offers images of resolution approximately 1000x1000 per wire (up to 4800 DPI). Because of all cylinders have the same physical size and wires inside them have not, an exact pixel resolution of each wire depends of its own size. Fortunately, diameters of the wires vary only slightly and so input images for image processing have similar resolution introduced above.

II. WIRES SEGMENTATION AND PRE-PROCESSING

The determination of the level of material segregation has to be performed for each individual wire in the cylinder. For this reason the wires should be segmented and isolated from the original image.

A. Wires Segmentation and Indexing

At first, a number of individual wires are recognized in the current cylinder by means of an ordinary thresholding [5]. The plastic surrounds of the wires is always very dark and so simple histogram analysis has been used to determine a proper threshold value [6]–[8].

As it can be seen in the Fig. 5, one or more wires can be connected together on their edges and such create only one logical object instead of two or more in sense of binary image (top left picture). To avoid this problem, several morphological operations are performed on the binary image as a result of the thresholding. First of all morphological erosion with a disc-shaped structure element is computed on the input binary image (top right picture). After that, an operation of indexing (sometimes called colouring) is done in an orthogonal grid. Each wire is then unambiguously marked with a number from 1 up to N , where N is the number of all wires in the current cylinder.

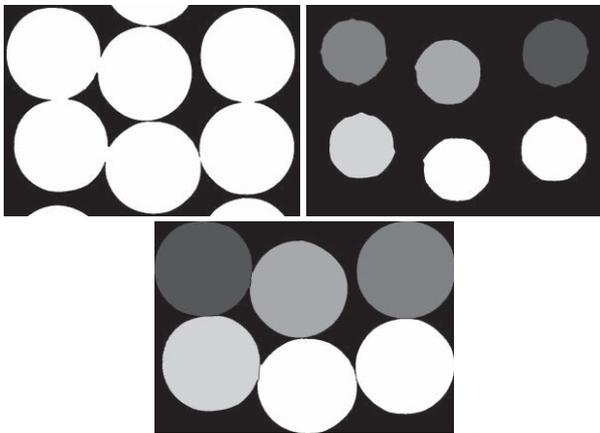


Fig. 5. The segmentation process of the steel wires in the cylinder.

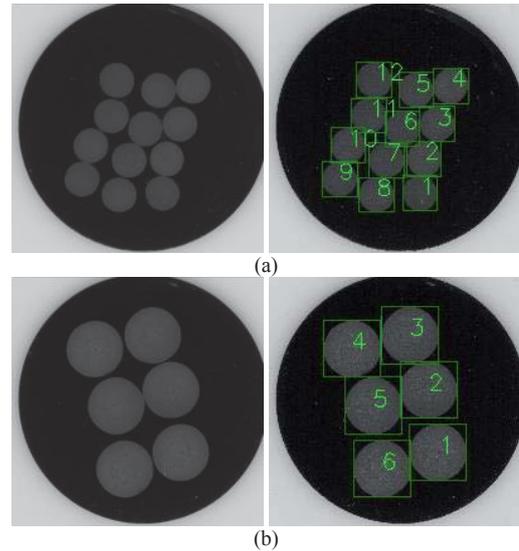


Fig. 6. The autonomous indexing in the zigzag scheme of (a) the twelve-wired and (b) the six-wired cylinder.

The last step at the segmentation stage is to restore wire's dimensions back to the original values (bottom middle picture). This step is carried out by a morphological dilation [5]. It follows the wires segmentation and indexing procedure is realized by means of the thresholding and subsequent morphological opening.

The final number of steel wires in the cylinder is then determined on the basis of the filtered binary image containing all segmented objects without a noise, dirt, scratches etc. Indexing of wires is performed in a so-called zigzag scheme which can be seen in the Fig. 6 for the both twelve-wired and six-wired cylinder respectively. The mentioned zigzag scheme is defined by the manufacturer and serves also for identification and verification purposes.

B. Image Pre-processing by Filtering

After the successful indexation, each wire is individually processed. Before the classification step, several pre-processing and filtering operations are performed [4]–[6].

Very often situation is that some dirt, scratch or dust is present inside the wire in the image. Fortunately almost all these defects have a higher brightness level than a rest of the wire, especially than the dark segregation region. These defects are filtered by detection of bright objects in an input image. Each pixel value of the bright object is then simply replaced by a representative average value given by its neighbourhood. As can be seen from the Fig. 7, bright dirt and objects similar to white thread (left picture) are detected and subsequently filtered by means of the error function (middle picture). The procedure results in an output image suitable for the next processing.

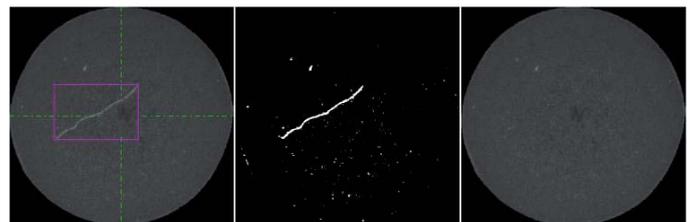


Fig. 7. White dust and dirt filtering in the input image of the wire.

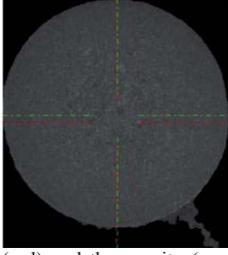


Fig. 8. The geometrical (red) and the gravity (green) centre of the wrongly segmented wire.

The well-known Gauss filtering was also carried out to reduce a noise and other high frequencies in the image. The last step in the image pre-processing section is to compute a centre of the wire. A position of the wire's centre is necessary for loops definition and computations of some statistical values in a classification stage. A simple and quick method based on a geometrical centre of the wire was designed and verified. Unfortunately this method had not good results in some special cases of wrong segmentation of the wire caused by a steel material outside a perimeter of the wire (see the previous Fig. 8). In such cases the centre of the wire is strongly influenced by a segmentation error (red lines in the picture) and an area of potential material segregation is then also significantly shifted. To avoid this inaccuracy, an alternative method was designed and implemented. The algorithm employs definition of the centre of gravity and so the resulting position of the centre is much more stable and moreover independent on similar segmentation errors (green lines in the picture above). On the basis of the wire's centre, the inspection loops are defined for later computations.

III. WIRE CLASSIFICATION

A. Definition of the Inspection Loops

Two loops have been defined for a detection and localization of the material segregation inside each wire. The loops definition is based on the fact, that the segregations are usually present only in the central part of the wires. So a first, inner loop then defines an area of a potential segregation in the centre of the wire. A second, outer loop defines an area without any useful information along the perimeter of the wire. Both loops are depicted in the Fig. 9 by light-blue circles. An area between these two loops is so-called an active area. This region (situated in the middle of the Fig. 9) is considered as segregation free and it is usable and very important for computation of statistical values of the wire, because these values are not affected by the dark segregation area in the centre of the wire. Especially the average pixel value μ and the standard deviation σ of the wire are calculated for a next step.

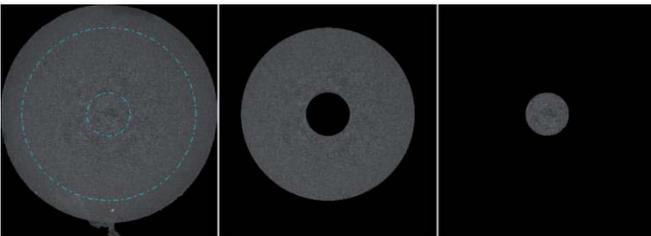


Fig. 9. The inner and outer loops define the active and the segregation areas.

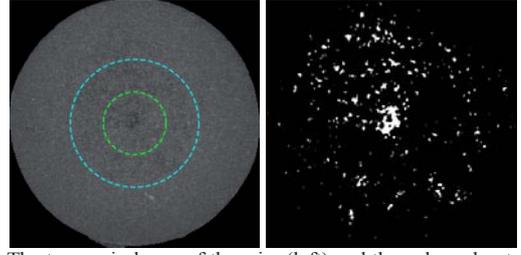


Fig. 10. The two main loops of the wire (left) and the enlarged output image of the segmentation process – thresholding (right).

B. Detection of the Inhomogeneous Objects

The most important step in evaluation process is to detect all inhomogeneous objects in the central part of the wire. To achieve this, an adaptive thresholding is performed inside the active area of the wire [9]. An input image with the depicted loops and a result of thresholding operation are both shown in the Fig. 10. An equation for determination of the threshold value corresponding to the mentioned thresholding operation is given by:

$$thr = \mu - c_{thr} \cdot \sigma \quad (1)$$

where symbol thr denotes the threshold value used for the segmentation, μ is the average pixel value of the active area, the σ is standard deviation of this area and finally c_{thr} represents weight coefficient (sensitivity).

As can be seen from the Fig. 10, lots of potential segregation objects are detected. Each one is later assessed by a value representing its own importance.

C. Objects Classification

As it was mentioned in the previous chapter, each detected object represents the potential segregation. For that reason, only very small and isolated objects are filtered as a noise [10]. Vice versa, each remaining object is then assessed by one value named WSA (*Weighted Sum of Area*). The value of the WSA is given by the following formula:

$$WSA(L) = \sum_{p \in L} \left(\frac{thr - p}{\sigma} \right)^2 \quad (2)$$

where the symbol L generally represents a current object and the p denotes pixels values within this object. In the next Fig. 11 the input image with a recognizable segregation and the output map with coloured objects are depicted side by side. The red one object in the centre of the wire refers to an object with the highest value of the WSA criterion. Others, blue coloured, objects are the less important inhomogeneous regions which are not involved in the classification step.

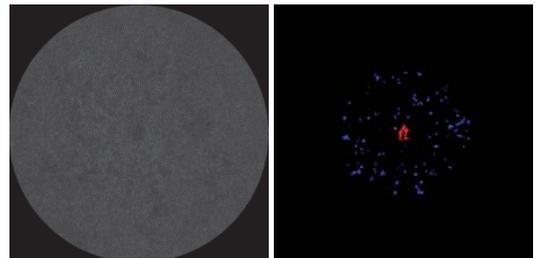


Fig. 11. The input image of the wire (left) and objects map (right).

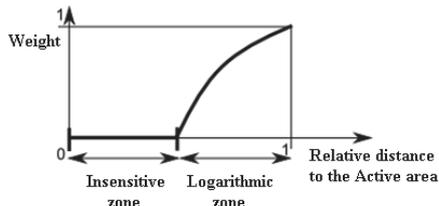


Fig. 12. The weighting function for the normalization of the WSA value.

The resulting value of the WSA criterion is finally normalized according to a distance between a centre of the current object and the centre of the wire. It means objects far from the centre of the wire are more penalized than the closest ones. This penalization is given by a weighting function depicted in the Fig 12. The reason of weighting is due to the material segregation is more probable in the centre of the wire than in the outer region.

The final step of the classification stage is a connection of the main segregation object (red) with some smallest objects. This step is necessary because of a real segregation area is often fragmented. Unfortunately a detailed description of the connection procedure goes beyond a scope of this paper.

However, the final segregation class is assigned to the object of segregation on the basis of its normalized WSA criterion. As it was already mentioned, the segregation classes are defined by the industrial standard and were introduced in the first chapter of this paper. Each segregation object is then classified e.g. as the GN, UL-A, UL-B, ZL-A etc. There are 24 classes defined in the standard, but only segregations of the GN, UL and ZL classes occur in the real plants. Described sequence of the pre-processing and segmentation methods was progressively implemented in several versions of the application Segregation Analyser and a lot of experiments and measuring were carried out.

IV. EXPERIMENTS AND RESULTS

Images of almost 300 cylinders were obtained for the reasons of the verification experiments. Each cylinder usually contained six or twelve wires. The constellation with the twelve wires is the most frequent and so more than 3000 images of wires have been at disposal for experiments. The main test was about accuracy of classification and also about difference between classification by a human inspector and the designed application. The human inspectors were well experienced workers from the metallurgical laboratory and the two last versions of the Segregation Analyser application have been involved in the tests (versions denoted as 2.2 and 3.1). The following Table I. introduces the percentage values of a consensus level between classification by a human inspector and by the application.

TABLE I
COMPARISON BETWEEN AUTONOMOUS AND HUMAN CLASSIFICATION –
PERCENTAGE CONSENSUS LEVEL

Segregation Class	Human vs. SA2.2	Human vs. SA3.1
GN	67.9 %	81.6 %
UL	78.7 %	59.9 %
ZL	7.1 %	35.7 %
Weighted Total	70.0 %	69.2 %

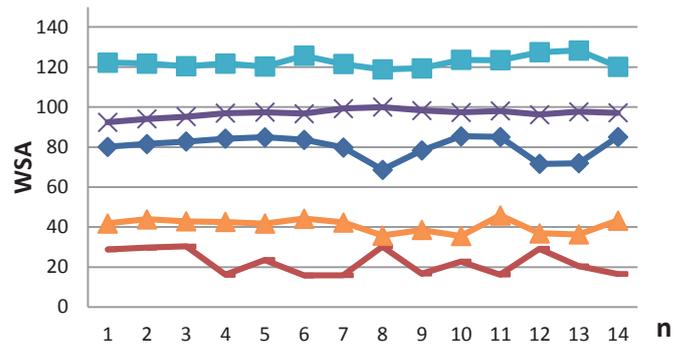


Fig. 13. The sets of the WSA criterion for five repeatedly scanned wires.

The second set of tests was about stability of the classification. In this stage a lot of wires under various transformations e.g. rotation were classified repeatedly by our algorithm. A small example of such verification is depicted in the Fig. 13. The index n on the horizontal axis represents repeatedly classified wire and the relevant WSA value is on the vertical axis. For instance above, each wire has been scanned 14 times and five selected wires were compared together. As can be seen, stability of the objects with a lower value of the WSA criterion is lower in comparison with the objects corresponding with high values of the WSA. In the all cases, however, the accuracy of the classification is sufficient.

V. CONCLUSION

A complete sequence of the image acquisition and processing methods for the classification of segregations was introduced in this article. All designed algorithms have been implemented and verified in the Segregation Analyser application and installed in the metallurgical laboratory for segregations analysis. Achieved results have been evaluated as satisfied and only minor changes and requested improvements are performed under the current needs.

REFERENCES

- [1] Russ, J.C. "The Image Processing Handbook". CRC Press Inc., Boca Raton Florida, 1994. ISBN 0-8493-2516-1.
- [2] Vernon, D. "Machine Vision: Automated Visual Inspection and Robot Vision". Hemel Hempstead : Prentice Hall International Ltd., 1991. 260 p. ISBN 0-13-543398-3.
- [3] Jensen, J. R. "Introductory Digital Image Processing: a remote sensing perspective". Prentice Hall. 2005, 526 pages. ISBN 0131453610.
- [4] Young, I.T., Gerbrands, J.J., Vliet, L.J. "Fundamentals of Image Processing". TU Delft, 1998. 113 p. ISBN 90-75691-01-7.
- [5] Sonka, M., Hlavac, V., Boyle, R. "Image Processing, Analysis and Machine Vision". Toronto : Thomson, 2008. 829 p. ISBN 978-0-495-08252-1.
- [6] Gonzales, R. C., Woods R. E. "Digital Image Processing - Third Edition". Pearson Education, Inc. 2008, 954 pages. ISBN 978-0-13-168728-8.
- [7] Nikhil, R. P., Sankar, K. P., "A review on image segmentation techniques", *Pattern Recognition*, Volume 26, Issue 9, September 1993, Pages 1277-1294, ISSN 0031-3203.
- [8] Kropatsch, W. G., Bischof H. "Digital Image Analysis". Springer-Verlag New York, Inc. 2001, 505 pages. ISBN 0-387-95066-4.
- [9] Horak, K., Richter, M., Kalova, I. "Automated Flaws Detection on Bottles in Food Industry", The proceedings of the 20th International DAAAM Symposium, pp. 133-135, 2009, ISBN 978-3-901509-70-4.
- [10] Papageorgiou, C.P., Oren, M., Poggio, T. A "General Framework for Object Detection", *Proceedings of the 6th International Conference on Computer Vision*, pp. 555-562, 1998, IEEE Computer Society, Washington. ISBN 81-7319-221-9.