

Study on signs of defects in the image of the surface of flat-rolled products

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Abstract. Currently, more and more challenges of modern industrial enterprises require an increase in the reliability of the information on the quality of products. This becomes possible when using digital technologies to assess the quality of products. The cited publication discusses the technology for recognizing defects in the surface of sheet products in images obtained from cameras of the strip inspection system during rolling. The authors proposed a classification of the signs of defects in the image and highlighted the most significant of them also suggested using geometric, optical and spectral features for images of flat-rolled products containing defects of different classes. The research results at this stage, obtained during the processing of digital images, showed that to identify a defect and reduce false-positive and false-negative alarms of the automated defect identification system, it is required to conduct a study of interval estimates and make decision-making rules based on intersection and merging of intervals; introduce additional classes that allow the introduction of signs that characterize the irregularity of the shape of defects and the characteristic location; the use of new technologies of soft computing will reveal the hidden patterns of the manifestation of defects in the images of the surface of the steel strip.

1 Introduction

Cold-rolled steel with subsequent annealing and galvanized coating is used in industry for the manufacture of car bodies, housings for household appliances and the construction industry. The quality of the metal surface is one of the key criteria for the consumers [1]. When assessing the surface quality, both organoleptic methods and *automated systems for recognizing surface defects* (ASRSD) are used that analyze images of the rolled surface obtained at the sections of the , such as a *continuous galvanizing aggregate* (ACG) and a *continuous hot-dip galvanizing aggregate* (AHG) of PJSC Magnitogorsk Iron and Steel Works "(PJSC" MMK ") ASRDP, used in production, structurally consist of sensors, network interfaces, a defect detection unit, a database [2] (Fig. 1).

The sensors consist of several cameras, physically combined into a single unit, installed at the top and bottom of the strip. The existing ASRSD has a sufficiently high accuracy in detecting defects, however they have drawbacks too. The main disadvantages include false positive and false negative positives and incorrect determination of the defects. These disadvantages lead to an increase in production costs, so, for example, a large number of false positives enlarge the number of labor who needs to inspect each section and decide on the presence of defects. False negative alarms lead to the fact that products with a defect are sent to the consumer, who forms a complaint. Furthermore, a false determination of the class of defect does not allow making a timely corrective action on the unit or on previous production redistributions. It is therefore essential for eliminating the shortcomings to develop a more accurate method for assessing the quality of the strip surface. Modern methods of image pattern recognition include several stages, such as removing noise [3], determining the region of potential defect location, highlighting the defect area, determining the values of image features, followed by using neural networks to determine the defect class. The features of objects in the image are considered in [4-12]. In [8], the features of images are considered for further use of features in the classification of a defect.

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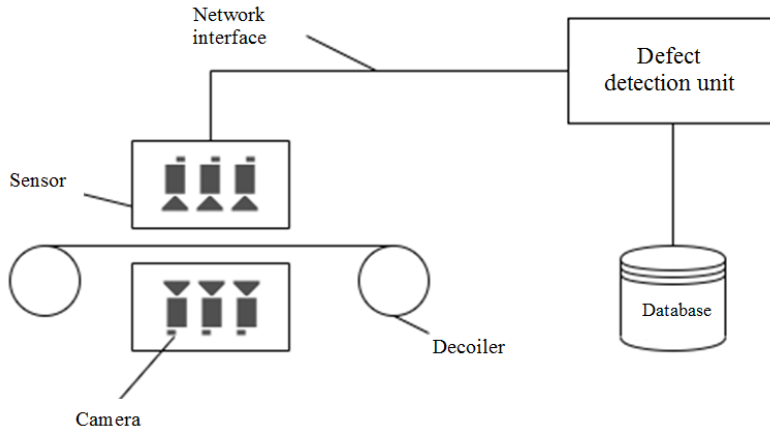


Fig. 1. Structure of automated systems for recognizing surface defects

2 Research methods

2.1. Classification of signs of defects on the surface of steel plate

The result of the work of the ASRSD is a set of digital images that are subjected to automated processing. The digital image supplied to the input of the defect detection unit is set by the values of the pixel brightness. To identify and classify defects on the surface of a metal sheet, it is necessary to enter features. The experts in the field proposed a classification of signs of defects by signs: geometric parameters, optical signs by brightness and spectral signs by the presence of texture Fig. 2.

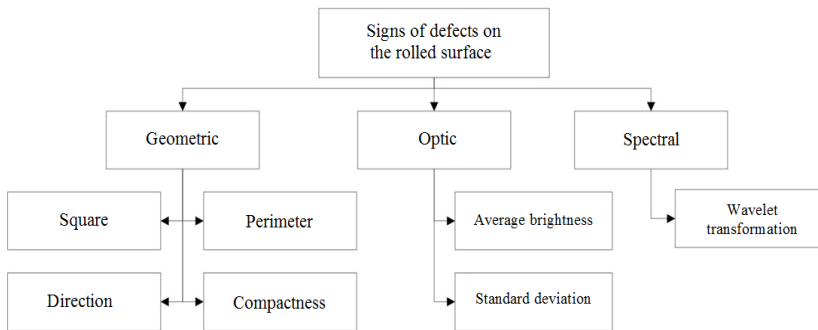


Fig. 2. Classification of signs of defects on the surface of steel sheet

For each feature, quantitative characteristics have been introduced, which make it possible to identify the presence of a defect on the surface in automatic mode.

2.2. Quantitative characteristics of signs of defects

Table 1. Formulas for quantifying geometric features

Description	Designation	Formula
Defect area - the number of points on the binarized image that belong to the defect zone	S	$S = \sum_{(x,y) \in R} 1$
Perimeter - the number of points on the border of the defect area	P	$P = \sum_{(x,y) \in G_R} 1.$
Compactness - dimensionless quantity invariant to changes in scale and rotation	q	$q = \frac{P^2}{S}$
The direction of the defect [9] relative to the movement of the strip - the angle between the line drawn in the middle of the smaller circumscribed rectangle and the direction of movement of the strip	α	An example of determining the angle is shown in Figure 3.

Notice: The table contains designations: R – defect area; G_R – defect boundary

For the class of geometric features, formulas are introduced (see Table 1). The value of compactness takes on a minimum value for a shape close to a circle, which corresponds to such defects as holes and technological apertures when marking the welding spots of coils.

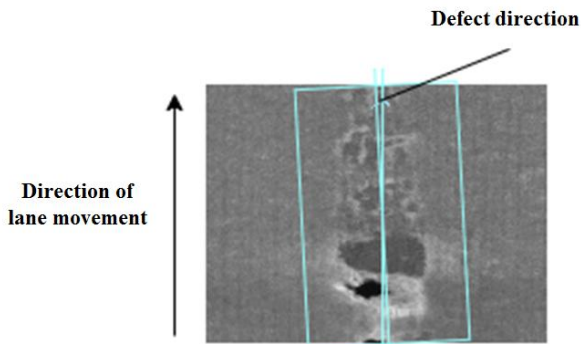


Fig. 3. Scheme for determining the direction of a defect on the rolled surface

For the class of optical features, a formula is used to calculate the average image brightness and the standard deviation from the average brightness.

Average value of brightness of defect pixels:

$$b = \frac{1}{S} \sum_{(x,y) \in R} I(x,y);$$

here $I(x,y)$ – two-dimensional matrix of brightness values of the image received from the ASRSD

The standard deviation of the brightness of the image obtained from ASRSD:

$$\sigma = \sqrt{\frac{1}{S} \sum_{(x,y) \in R} (b - I(x,y))^2}.$$

For spectral features, the formulas were used for calculating the wavelet transform coefficients given in [10]:

$$bw_z^j = \frac{1}{n_j} \sum_{(x,y) \in R} w_z^j(x,y),$$

When i – wavelet transform level 1,2; z – conversion direction is horizontal, vertical and diagonal; w_z^j – wavelet transform coefficient at level i in direction z ; n_j – the number of points of the defect area at the $-m$ level of the wavelet transform.

3 Results and Discussions

Information gained from accumulated in the conditions of operation in the conditions of the sheet-rolling shop of PJSC "MMK" made it possible to calculate the signs of defects. As a test example, images of surface defects of different classes were selected: scale (Fig. 4a), transverse cracks (Fig. 4b), and annealing tear (Fig. 4c).

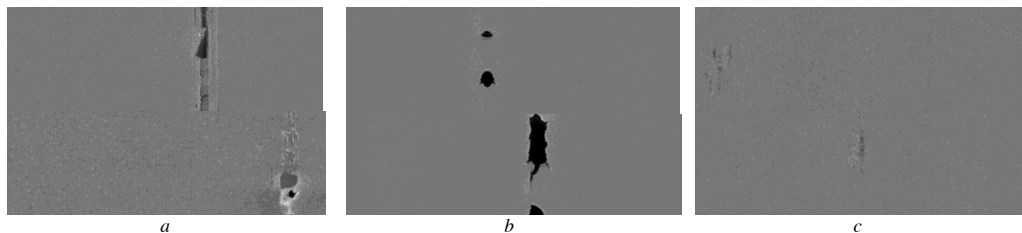


Fig. 4. Image of the "scale" (a), "transverse cracks" (b) and "annealing tear" (c) defects on the surface of the steel sheet

The quantitative calculation process was carried out using a software product. The calculation results are shown in Table 2.

The results obtained allow asserting the presence of interval estimates of the image for each feature and each type of defects. These estimates can be used to construct complex rules for making a decision on the presence and type of defect on the surface of flat-rolling product.

In the state policy of modern states, the red line is the challenge of introducing and developing digital technologies on production platforms. The level of development of computer technology, software and fundamental research in the field of image processing allow these technologies to be adapted to heavy industry and, in particular, to ferrous metallurgy. The present investigation in this area [13-16] has once again shown that the fundamental algorithms for processing digital images, on the one hand, are of the same type, but on the other hand, they require refinement and adaptation to the conditions of the problems being solved. Under the conditions of the above study, it is required to expand the classification features and develop decision-making techniques based on interval estimates. It is to the issues of that further research on the above topics will be devoted.

Table 2. Feature values for different classes of defects

Defect symptom	Defects		
	Scale	Transverse cracks	Annealing tear
Square	644 ... 6288	139...1735	99 ...1679
Perimeter	144 ... 1819	94...308	72...378
Compactness	146 ... 526	23 ... 69	55...127
Direction	-5 ... +5	78 ... 93	15...90
Average brightness value	62...101	24...48	21...100
Root mean square deviation	18...23	15...29	11...22
1 st order wavelet coefficients	31 ... 50	13...29	7...32
2 nd order wavelet coefficients	15 ... 24	6...13	15...69

4 Conclusions

- To determine the presence of a defect on the surface of a steel strip, it is proposed to use three classification criteria at the first level: geometric, optical and spectral.
- For each class, quantitative measures have been introduced, which are necessary to identify the fact of the presence of a defect on the surface.
- For a test sample of images, all quantitative parameters of each class were calculated using a software product.
- The calculation results made it possible to obtain an interval estimate that can be used to identify a defect and reduce false-positive and false-negative alarms of the ASRSD.
- To increase the accuracy of determining the class and type of defect, it is required:
 - carry out a study of interval estimates and make decision rules based on the intersection and merging of intervals;
 - to introduce additional classes that allow the introduction of signs that characterize the irregularity of the forms of defects and the characteristic location;
- The use of new technologies of soft computing reveals the hidden patterns of the manifestation of defects in the images of the surface of the steel strip.

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