REVIEW Open Access

Review of vision-based steel surface inspection systems

[illegible]

Abstract

[illegible]

Keywords: [illegible]

Review

1. Introduction: importance of steel surface and its automated inspection

[illegible]

2013 1,5 2 ( ), 3,500 50%.

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5. Categories of steel surfaces

- *Slab/billet*: both are produced by continuous casting process from liquid steel and have some similarity with respect to surface and internal conditions. Surface is scale covered and more grainy.
- *Plates* are produced by reheating a slab at about 1,250°C and rolled subsequently. The surface is oxidised and comparatively even with respect to that of slab.
- *Hot strips* are produced by reheating a slab at about 1,250°C and rolling in multiple rolling stands to reduce the thickness to desired value. The strip surface is oxidised. However, due to high rolling force, the surface granularity of hot strip is considerably reduced compared to slab.
- *Cold strips* are produced by rolling hot strips in cold rolling mill after pickling process (which removes the oxide layer and cleans the surface). Thus, the surface of cold strips is not oxidised, and the surface is quite smooth due to very high rolling forces used in cold deformation process.
- *Coated strip (galvanised, tinned)/finished stainless strip* surfaces are highly reflective in nature.

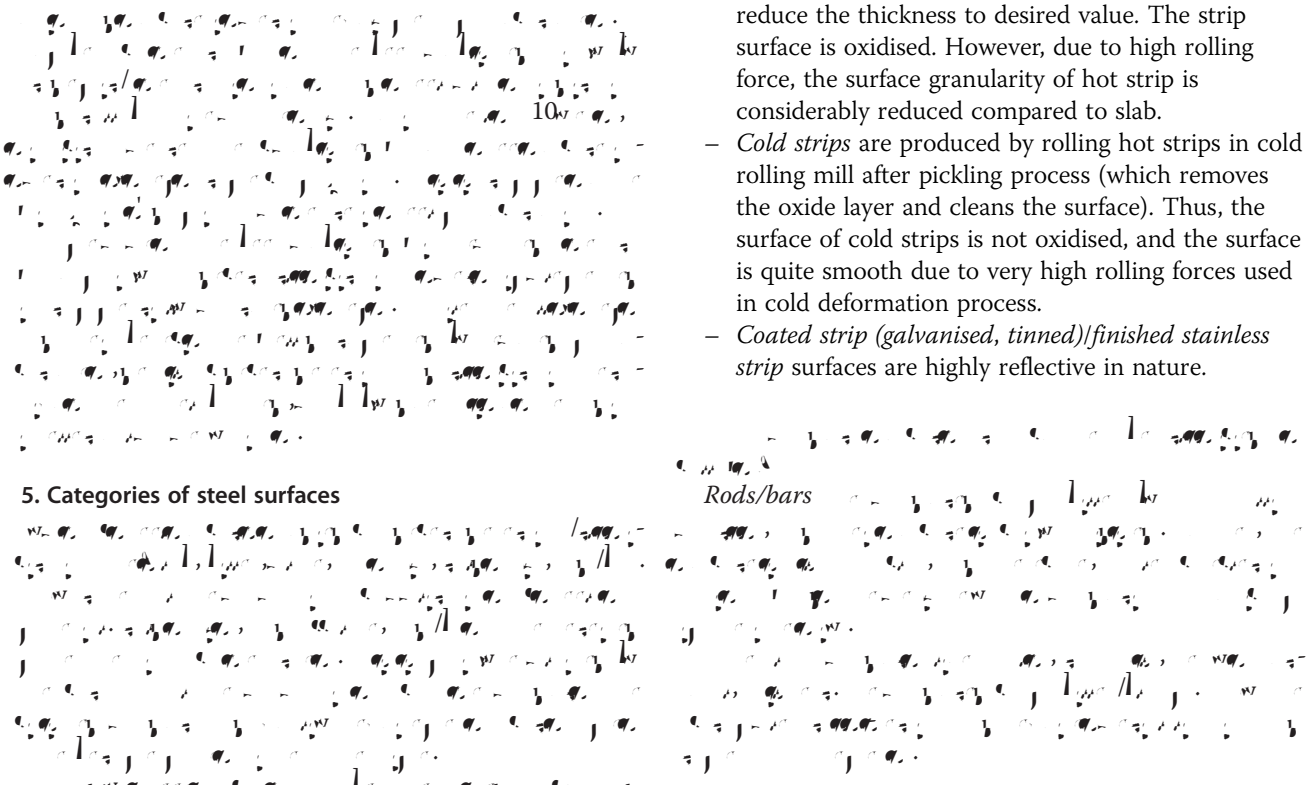

Figure 2 Categories of steel products.

Rods/bars

6. List of surface defects for steel products

Slab: cracks (on surface and corner), pitting (pinhole and blowhole), scratch, scarfing defects.
Plate: crack scratch, seam.
Billet: corner crack, line defect, scratch.
Hot-rolled strip: hole, scratch, rolled in scale, crack, pits/scab, edge defect/coil break, shell, lamination, sliver.
Cold-rolled strip: roll marks, holes, scratches, dark/black line, heat buckle, rust, sliver, scale, roll mark, oil spot, serrated edge, wrinkle, inclusion, shell, pimple, oxide scale, lamination.
Stainless steel: holes, shells, inclusions, blowhole, scales, scratches, pimples, roll mark.
Wire rod/bar: crack, spot, dark line, laps, overfill, scratches, gorges, seams, slivers, roll mark.

7. Key elements of automatic surface inspection system hardware structure

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7.1 Image acquisition

1 -22

23 .

3

21 .

24-2 . 20

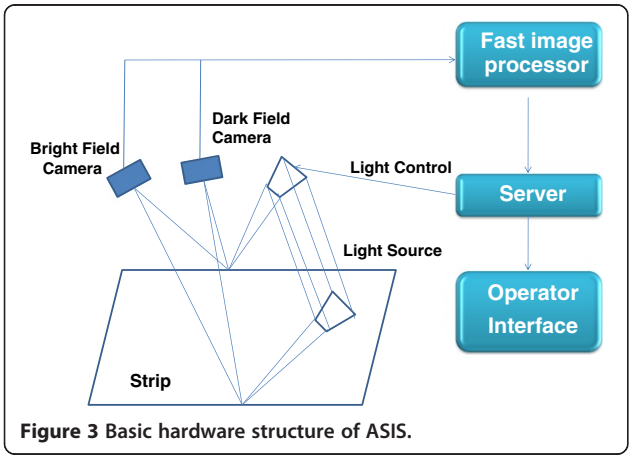

Figure 3 Basic hardware structure of ASIS.

24 .

7.2 Source of light

2

4

2 .

7.3 Type of camera

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7.4 Camera and image resolution

Camera resolution.

1,024( ) 1( ) 2,04 1 .

. 31 4,0 1 .

1,024/2,04 /4,0 1 .

00 400 32 .

33 , 4,0 1,000 .

Image resolution.

24,2 ,31,33,34 . .

0.1 1

0.25 1.25 .

7.5 Image processing computer hardware

24 .

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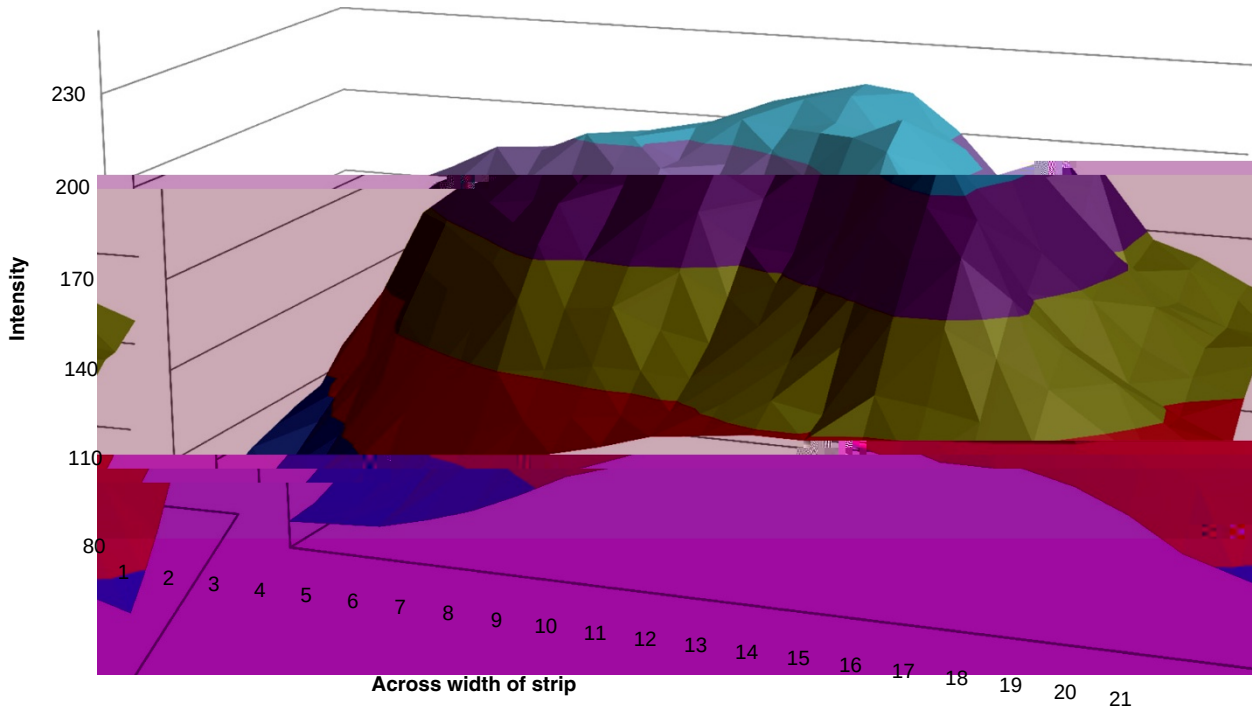

Figure 4 Illumination pattern [29].

8. List of defect detection and classification methods

9. Comparative evaluation of defect detection systems

Discussions on defect detection methods.

Table 1 List of defect detection methods

Method	Reference	Type of steel surface
	35	
	36	
	37	
	34	
	33,38-40	
	41	
	42,43,31,1	
	44	
	45	
	40,46,47	
	48,49,24,50	
	51,52,43,25,53-55,3,31,56,26,1,57	
	58,44,59-61,2	
	62	
	63	
	64-66,33,67,29,38,68,69,39	
	70,28,41	
	71,17,72 ,	
	73-75,5,60	
	63,76	

3,35,41,42,5 ,5 , 1 ,

9.1 Pre-processing

5

25,43

4

5,44,5 ,5

1

Table 2 List of defect classification methods

Method	Reference	Type of steel surface
	1	
	37	
	28,32,36	
	77,54,63,31,78,79,72,80	
	59	
	64,65,33,67,47	
	70,24	
	81,82,25,83,84	
	85,44,5,2 ,	
	86	
	80	
	42,35	
	25,87,76,88	
	36	
	43,34	
	62	
	89	

5,44 ( ) 5 ( ).

44

9.2 Spatial domain-based methods

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2,24,2 ,35,4 ,5 ,5 , 1,

2,44,4 ,5 ,

2,24,5 ,

24,31,5 .

(5%) .331

24

2 ,

Table 3 Comparison of defect detection systems

Paper	Method		Type of defects	Sample size	Features	Detection accuracy (%)	Resolution (across × along)	Speed of steel object (m/s)	Real-time operation	Remark
	Detection	Classification								
67 -				7,110	7	94.08				
29 -				1,764	4	87.1	0.57 0.5			
38 -				1,568	4	97.6				
64 -				220-	12	97.8	0.25	2		
65 -				10,459	12	84.83	0.5			
41 -				563-		90.23				
24 -				8,037		>90	0.5 0.5	10		

Table 3 Comparison of defect detection systems *(Continued)*

61 -			175 (73-)		95.42		18.5	
58 -			408-		93.88 100		4.6	
60 -	2		400	7 9	97.5		18	
44 -			2,444	42	96.9	0.3	18.5	
2 -			1,226		94.4		100	
5 -			2,080	14	91.83	0.5	18	
75 -			6		100	0.5	18	
59 -			663-	12	85.82	89	15	

Table 4 Comparison of defect classification systems

Paper	Method		Type of defects	Sample size	Features	Classification accuracy (%)	Resolution (Across x along) (mm)	Speed of steel object	Real-time operation
	Detection	Classification							
46					17		0.076 1.27	4 (36.6)	
70			24	1,432	3 9 5	93.8	1 1	20	
36		N		1,084	24	83.5			
62				485	54	84 93			
32				255	4	98.75		10 15	
31				2,300	9	: 97, : 82	0.37		
76				15 20		85 95		6	
26				196		95.5	0.17 1.25	1,400 (23)	
89				135	17 +11	68 96		5	
63				2,300	10	97.9	0.37		
43		N		300	6	: 98. : 77			
87				212	4	95			
83				1,200	54	92.4			
82				500		94			
77				300		94.34			

Table 4 Comparison of defect classification systems *(Continued)*

59 -			663-	12	: 90.66, : 91.21		15 /
85 -		( )	600 (20,140)	4 +	81.4	93.9	

9.3 Wavelet-based methods

24

4%

9.4 Use of fractal model

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10. Comparative evaluation of defect classification systems

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Discussions on defect classification methods.

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10.1 Neural network with back propagation (NN-BP)

31,3 ,54,5 , 3, 2, , 0 .

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2 24)

31,3 ,

3

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/

31 ,

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2% (%)

10.2 Support vector machine (SVM)

10.3 Unsupervised classifier

Table 5 Algorithm processing time - comparative table

Paper	Method	Max. speed of steel object (m/s)	Resolution (across × along)	Suitability for real-time operation (as reported)	Processing time per image: total
64		2	0.25		93.7 (- 8.34 - 76.98 - 8.38)
70 -		20	1 1	5 /	178 (- 38 - 44.5 - 95.5)
61 -		18.5			8.33 : 3.4 : 4.93
58 -		4.6			13 (- 2 + 3 - 8)
2 -		. 100			5.8 (-5.6 -0.16)
75 -		18	0.5		7.315 , 74.747

43 , ( ) 20 20 % 34 %

11. Algorithm processing time

Q Q Q 5 . 5, (2 100 /). 100 / 5.5- 20 / 4 / 20 / 3 4, 0.25 1.25 / 0.5 500 20 / , 0 (12.5 /)

12. Comparative studies

3 10.1 10.3. 52 (( )) 2 2 ( ) (4%) 3 31 3 , ( ), 31 , %.

13. Steel surface automated inspection system: overview of commercial developments

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0301/03.02.2010).

Conclusions

a) Due to harsh environment of a steel mill, special attention is required for design of illumination and imaging systems. Steel surface images are reported to contain large amount of noise due to surface scale, vibration, improper/variable illumination, presence of pseudo defects etc. Surface defects are of irregular shape and their type and characteristics vary significantly from one mill to another. Characteristics of defects are also dependent on conditions of manufacturing.

b) Published literatures indicate that relatively more importance has been given to detection of defects for cold strip surfaces. Recently, attention is also focussed on surfaces of hot strips and bars/rods. A large variety of techniques, both in spatial and frequency domains, have been applied for defect detection. Often, combination of several techniques has provided useful results. With respect to defect classification, some form of neural network or support vector machine-based techniques have been found to be of use. Real-time operation of automated inspection system often demands very fast processing of images as mill speed is generally very high for flat and long steel products. This calls for dedicated hardware system with parallel processing capability for each camera.

c) It is not prudent to compare outcome of different techniques due to lack of common standard with respect to images and experimental methods. This problem is further complicated due to lack of standard definition of defect types.

d) Commercially produced automated vision-based inspection systems for web materials have reached a high level of maturity. However, they are required to be properly 'tuned' for a particular application. Also, continuous collaboration between designer and user is necessary to adapt the installed system to new varieties/characteristics of defects at the same installation site.

Abbreviations

Competing interests

Author details

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