

Review of vision-based steel surface inspection systems

✉ Y. D. Cao^{1*}, Y. Y. Chen¹, Y. Y. Li¹, S. Q. Li², C. Y. Li²

Abstract

With the rapid development of steel surface inspection technology, vision-based steel surface inspection systems have become the mainstream of steel surface inspection. This paper reviews the research progress of vision-based steel surface inspection systems. The research progress is divided into three parts: hardware, software and application. The hardware part mainly reviews the research progress of camera, light source and image processing unit. The software part mainly reviews the research progress of image processing algorithm, feature extraction algorithm and classification algorithm. The application part mainly reviews the research progress of steel surface inspection system. The research progress of vision-based steel surface inspection systems is summarized, and the research trend is predicted.

Keywords: vision-based steel surface inspection system, image processing, feature extraction, classification

Review

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

Steel is one of the most important materials in modern industry. The quality of steel surface has a great influence on the performance of steel products. Therefore, the inspection of steel surface is an important link in the production process of steel. In the past, the inspection of steel surface was mainly carried out by manual inspection. However, with the rapid development of steel production, the manual inspection method has been unable to meet the requirements of production. Therefore, the automated inspection of steel surface has become the mainstream of steel surface inspection.

The automated inspection of steel surface is a complex system. It includes the hardware and software parts. The hardware part mainly includes the camera, light source and image processing unit. The software part mainly includes the image processing algorithm, feature extraction algorithm and classification algorithm.

The research progress of vision-based steel surface inspection systems is summarized in Table 1. The research progress is divided into three parts: hardware, software and application. The hardware part mainly reviews the research progress of camera, light source and image processing unit. The software part mainly reviews the research progress of image processing algorithm, feature extraction algorithm and classification algorithm. The application part mainly reviews the research progress of steel surface inspection system.

The research progress of vision-based steel surface inspection systems is summarized, and the research trend is predicted. The research trend is that the research progress of vision-based steel surface inspection systems will continue to improve, and the research trend will be towards the direction of high speed, high accuracy and high reliability.

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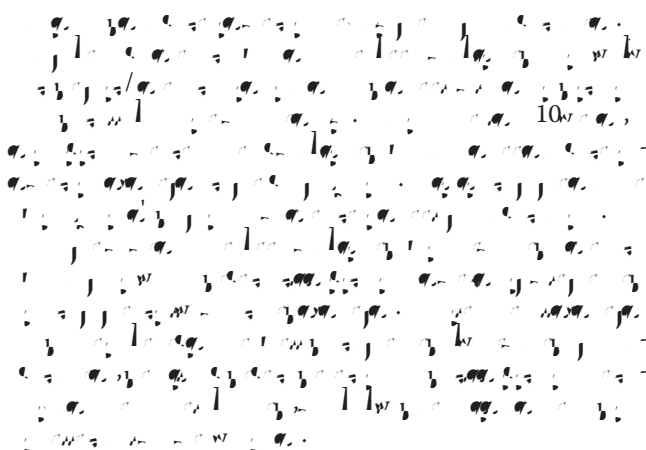
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$$\begin{aligned} \mathcal{W}_1 &= \{x \in \mathbb{R}^n : x = \sum_{i=1}^n \alpha_i \mathbf{v}_i, \alpha_i \geq 0, \sum_{i=1}^n \alpha_i = 1\} \\ \mathcal{W}_2 &= \{x \in \mathbb{R}^n : x = \sum_{i=1}^n \beta_i \mathbf{v}_i, \beta_i \geq 0, \sum_{i=1}^n \beta_i = 1\} \end{aligned}$$



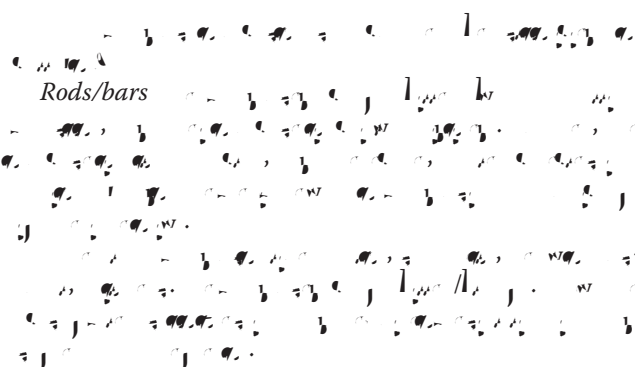
5. Categories of steel surfaces

Steel surfaces are categorized into three main types based on their production process and surface characteristics. The first type is *Hot-rolled strip*, which is 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. The second type is *Cold strips*, which 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. The third type is *Coated strip (galvanised, tinned)/finished stainless strip* surfaces are highly reflective in nature.

- *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.



6. List of surface defects for steel products

Steel products are categorized into three main types based on their production process and surface characteristics. The first type is *Hot-rolled strip*, which is 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. The second type is *Cold strips*, which 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. The third type is *Coated strip (galvanised, tinned)/finished stainless strip* surfaces are highly reflective in nature.

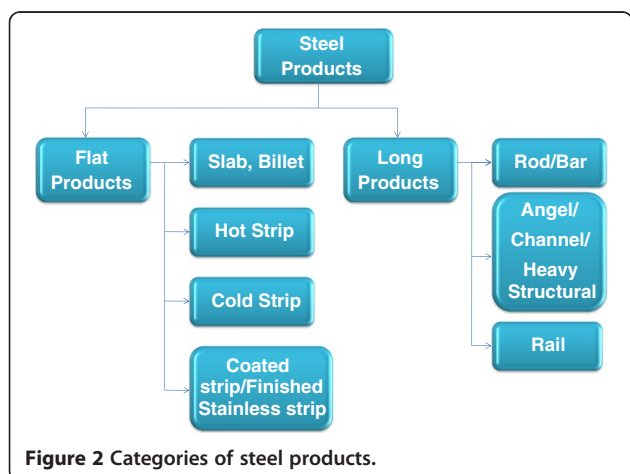


Figure 2 Categories of steel products.

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

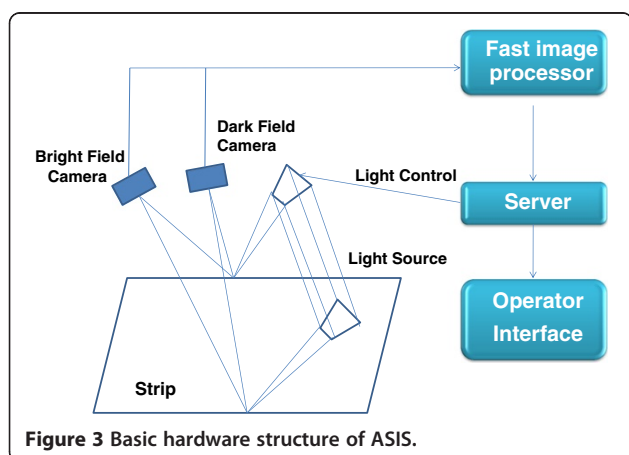
The hardware structure of the automatic surface inspection system (ASIS) is shown in Figure 3. The system consists of a Bright Field Camera, a Dark Field Camera, a Light Source, a Light Control, a Fast image processor, a Server, and an Operator Interface.

7.1 Image acquisition

The image acquisition process involves capturing images of the surface of the strip. The Bright Field Camera and the Dark Field Camera are used to capture the images. The Light Source and Light Control are used to illuminate the surface. The Fast image processor is used to process the images. The Server is used to store the images. The Operator Interface is used to control the system.

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7.2 Source of light

The source of light is used to illuminate the surface of the strip. The Light Source and Light Control are used to illuminate the surface. The Fast image processor is used to process the images. The Server is used to store the images. The Operator Interface is used to control the system.

7.3 Type of camera

The type of camera used in the ASIS is a Bright Field Camera and a Dark Field Camera. The Bright Field Camera is used to capture the images of the surface of the strip. The Dark Field Camera is used to capture the images of the surface of the strip. The Light Source and Light Control are used to illuminate the surface. The Fast image processor is used to process the images. The Server is used to store the images. The Operator Interface is used to control the system.

7.4 Camera and image resolution

Camera resolution. The camera resolution is 1,024 (horizontal) × 1,024 (vertical) pixels. The image resolution is 1,024/2,048/4,096/8,192/16,384/32,768/65,536/131,072/262,144/524,288/1,048,576/2,097,152/4,194,304/8,388,608/16,777,216/33,554,432/67,108,864/134,217,728/268,435,456/536,870,912/1,073,741,824/2,147,483,648/4,294,967,296/8,589,934,592/17,179,869,184/34,359,738,368/68,719,476,736/137,438,953,472/274,877,906,944/549,755,813,888/1,099,511,627,776/2,199,023,255,552/4,398,046,511,104/8,796,093,022,208/17,592,186,044,416/35,184,372,088,832/70,368,744,177,664/140,737,488,355,328/281,474,976,710,656/562,949,953,421,312/1,125,899,906,842,624/2,251,799,813,685,248/4,503,599,627,370,496/9,007,199,254,740,992/18,014,398,509,481,984/36,028,797,018,963,968/72,057,594,037,927,936/144,115,188,075,855,872/288,230,376,151,711,744/576,460,752,303,423,488/1,152,921,504,606,846,976/2,305,843,009,213,693,952/4,611,686,018,427,387,904/9,223,372,036,854,775,808/18,446,744,073,709,551,616/36,893,488,147,419,103,232/73,786,976,294,838,206,464/147,573,952,589,676,412,928/295,147,905,179,352,825,856/590,295,810,358,705,651,712/1,180,591,620,717,411,303,424/2,361,183,241,434,822,606,848/4,722,366,482,869,645,213,696/9,444,732,965,739,290,427,392/18,889,465,931,478,580,854,784/37,778,931,862,957,161,709,568/75,557,863,725,914,323,419,136/151,115,727,451,828,646,838,272/302,231,454,903,657,293,676,544/604,462,909,807,314,587,353,088/1,208,925,819,614,629,174,706,176/2,417,851,639,229,258,349,412,352/4,835,703,278,458,516,698,824,704/9,671,406,556,917,033,397,649,408/19,342,813,113,834,066,795,298,816/38,685,626,227,668,133,590,597,632/77,371,252,455,336,267,181,195,264/154,742,504,910,672,534,362,390,528/309,485,009,821,345,068,724,781,056/618,970,019,642,690,137,449,562,112/1,237,940,039,285,380,274,899,124,224/2,475,880,078,570,760,549,798,248,448/4,951,760,157,141,521,099,596,496,896/9,903,520,314,283,042,199,193,993,792/19,807,040,628,566,084,398,387,987,584/39,614,081,257,132,168,796,775,975,168/79,228,162,514,264,337,593,551,950,336/158,456,325,028,528,675,187,103,900,672/316,912,650,057,057,350,374,207,801,344/633,825,300,114,114,700,748,415,602,688/1,267,650,600,228,229,401,496,831,205,376/2,535,301,200,456,458,802,993,662,410,752/5,070,602,400,912,917,605,987,324,821,504/10,141,204,801,825,835,211,974,649,643,008/20,282,409,603,651,670,423,949,299,286,016/40,564,819,207,303,340,847,898,598,572,032/81,129,638,414,606,681,695,797,177,144,064/162,259,276,829,213,363,391,594,354,288,128/324,518,553,658,426,726,783,188,708,576,256/649,037,107,316,853,453,566,377,417,152,512/1,298,074,214,633,706,907,132,754,834,305,024/2,596,148,429,267,413,814,265,509,668,609,048,048/5,192,296,858,534,827,628,531,019,337,217,616,096/10,384,593,717,069,655,257,062,038,674,353,232,192/20,769,187,434,139,310,514,124,077,348,666,464,384/41,538,374,868,278,621,028,248,154,697,332,928,768/83,076,749,736,557,242,056,496,309,394,665,857,536/166,153,499,473,114,484,112,992,618,789,331,715,072/332,306,998,946,228,968,225,985,237,578,662,140,144/664,613,997,892,457,936,451,970,475,157,324,280,288/1,329,227,995,784,915,872,903,940,950,314,648,560,576/2,658,455,991,569,831,745,807,881,900,629,127,121,152/5,316,911,983,139,663,491,615,763,801,258,254,242,304/10,633,823,966,279,326,983,231,527,602,516,508,484,608/21,267,647,932,558,653,966,463,055,205,033,016,969,216/42,535,295,865,117,307,932,926,110,410,066,033,938,432/85,070,591,730,234,615,865,852,220,820,132,067,876,864/170,141,183,460,469,231,731,704,441,640,264,135,753,752,128/340,282,366,920,938,463,463,408,883,280,528,271,507,504,256/680,564,733,841,876,926,926,817,766,561,056,543,015,008,512/1,361,129,467,683,753,853,853,635,533,122,108,603,001,024/2,722,258,935,367,507,707,707,271,066,244,217,206,002,048/5,444,517,870,735,015,415,414,542,132,488,434,412,004,096/10,889,035,741,470,030,830,829,084,264,868,868,824,008,192/21,778,071,482,940,061,661,658,168,529,737,737,648,016,384/43,556,142,965,880,123,323,316,337,059,475,475,296,032,768/87,112,285,931,760,246,646,632,674,118,950,950,592,065,536/174,224,571,863,520,493,293,265,348,237,901,901,184,111,072/348,449,143,727,040,986,586,530,696,475,803,802,368,222,144/696,898,287,454,081,973,173,161,392,947,607,604,736,444,288/1,393,796,574,908,163,946,346,322,785,895,215,209,472,888,576/2,787,593,149,816,327,892,692,645,571,790,430,418,945,777,152/5,575,186,299,632,655,785,385,281,143,580,861,837,891,504/11,150,372,599,265,311,570,770,562,287,161,723,675,783,008/22,300,745,198,530,623,141,541,124,544,323,447,351,566,016/44,601,490,397,061,246,283,082,249,088,686,894,703,132,032/89,202,980,794,122,492,566,164,498,177,373,789,406,264,064/178,405,961,588,244,985,132,328,996,346,747,572,812,528,128/356,811,923,176,489,970,264,657,992,693,495,145,625,056,256/713,623,846,352,979,940,529,315,985,386,990,291,250,112,512/1,427,247,692,705,959,881,058,631,771,773,980,582,500,200,224/2,854,495,385,411,919,762,117,263,543,547,961,165,000,400,448/5,708,990,770,823,839,524,234,526,087,095,922,330,000,800,896/11,417,981,541,647,679,048,469,052,174,181,844,660,001,601,792/22,835,963,083,295,358,096,938,104,348,363,689,320,003,203,584/45,671,926,166,590,716,193,876,208,696,727,378,640,006,407,168/91,343,852,333,181,432,387,752,417,393,454,757,280,012,814,336/182,687,704,666,362,864,775,504,834,786,909,514,560,025,628,672/365,375,409,332,725,729,551,009,669,573,829,029,120,051,257,344/730,750,818,665,451,459,102,019,339,146,658,058,240,102,514,688/1,461,501,637,330,902,918,204,038,678,313,316,116,480,205,029,376/2,923,003,274,661,805,836,408,077,346,626,632,232,960,410,058,752/5,846,006,549,323,611,672,816,154,693,253,264,465,920,820,117,504/11,692,013,098,647,223,345,632,309,386,506,528,931,840,164,035,008/23,384,026,197,294,446,691,264,618,773,013,057,863,680,328,070,016/46,768,052,394,588,893,382,528,123,546,026,115,727,360,656,040,032/93,536,104,789,177,786,765,046,247,092,051,451,454,720,130,064,000,064/187,072,209,578,355,573,530,092,494,184,102,902,908,840,260,120,012,8/374,144,419,156,711,147,060,184,988,368,205,805,805,680,520,240,025,6/748,288,838,313,422,294,120,369,976,736,411,611,611,361,040,480,051,2/1,496,577,676,626,844,588,240,739,953,472,823,223,222,722,080,960,102,4/2,993,155,353,253,689,176,481,479,906,945,646,446,445,444,160,184,0/5,986,310,706,507,378,352,962,959,813,892,892,892,888,320,368,0/11,972,621,413,014,756,705,925,917,727,785,785,776,640,736,0/23,945,242,826,029,513,411,851,835,455,571,571,553,280,1472,0/47,890,485,652,059,026,823,703,671,143,143,106,560,2944,0/95,780,971,304,118,053,647,407,342,286,286,213,120,5888,0/191,561,942,608,236,107,294,814,572,572,526,240,11776,0/383,123,885,216,472,214,589,149,144,544,480,23552,0/766,247,770,432,944,429,178,298,288,1088,47104,0/1,532,495,540,864,888,858,356,596,576,2176,94208,0/3,064,991,081,729,777,716,713,193,1552,188416,0/6,129,982,163,459,555,433,426,386,3104,376832,0/12,259,964,326,919,111,086,852,772,6208,753664,0/24,519,928,653,838,222,173,705,545,2416,1507328,0/49,039,857,307,676,444,347,411,090,4832,3014656,0/98,079,714,615,352,888,694,822,181,966,6064,6029312,0/196,159,429,230,705,777,389,644,363,933,2128,12058624,0/392,318,858,461,411,554,779,288,727,866,4256,24117248,0/784,637,716,922,823,109,558,576,145,732,8512,48234496,0/1,569,275,433,845,646,219,117,111,291,4656,96468992,0/3,138,550,867,691,292,438,234,222,582,9312,192937984,0/6,277,101,735,382,584,876,468,445,165,186,28624,385875968,0/12,554,203,470,765,168,952,936,910,330,372,572,572,77152,771751936,0/25,108,406,941,530,337,905,873,820,660,745,145,114,514,114,154304,1543503872,0/50,216,813,883,060,674,811,747,640,130,140,228,228,228,308608,3087007744,0/100,433,627,766,121,349,623,494,280,260,256,456,456,617216,6174015488,0/200,867,255,532,242,698,246,988,560,520,512,912,912,1234432,12348030976,0/401,734,511,064,485,397,493,976,1040,1040,1824,1824,2468864,24696061952,0/803,469,022,128,970,794,987,952,2080,2080,3648,3648,4937728,49392123904,0/1,606,938,044,256,1,941,589,976,1975,904,7360,7360,9875456,98784247808,0/3,213,876,088,512,3,883,179,952,3951,808,14720,14720,19750912,197568495616,0/6,427,752,177,024,7,766,359,904,7903,616,29440,29440,39501824,395136991232,0/12,855,504,354,048,15,532,719,808,15,807,232,58880,58880,79003648,790273982464,0/25,711,008,708,096,31,065,439,616,31,614,464,117760,117760,158007296,1580547964928,0/51,422,017,417,192,62,130,879,232,63,228,928,31,603,232,31680,31680,416014592,4161095929856,0/102,844,034,834,384,124,261,758,464,126,456,18560,18560,832029184,8321191859712,0/205,688,069,668,768,248,523,516,928,252,912,37120,37120,1664058368,16642383719424,0/411,376,139,337,536,497,047,033,856,505,824,74240,74240,3328116736,33284767438848,0/822,752,278,674,072,994,094,067,712,1011,648,148480,148480,6656233472,66569534877696,0/1,645,504,557,348,144,1,988,188,013,424,2023,296,296960,296960,13312466944,133139069755392,0/3,291,009,114,696,297,376,397,636,848,4046,592,593920,593920,26624933888,266278139510784,0/6,582,018,233,392,594,752,795,273,696,8093,184,1187840,1187840,53249867776,532556279021568,0/13,164,036,466,784,1,189,504,1590,547,3875,376,2375680,2375680,106499735552,1065112558043136,0/26,328,072,933,568,2,379,008,3181,094,7750,752,4751360,4751360,212999471104,2130225116086272,0/52,656,145,867,136,4,758,016,6362,188,15501,1504,9502720,9502720,425998942208,4260450232172544,0/105,312,291,734,272,9,516,032,12723,76,31002,3008,19005440,19005440,851997884416,8520900464345088,0/210,624,583,468,544,19,032,064,25447,52,62004,6016,38010880,38010880,1703995768832,17041800928690176,0/421,248,116,736,388,388,508,912,50,996,12032,12032,76079915376,7608360185698048,0/842,496,233,472,776,776,1017,824,101,992,24064,24064,152159830752,15216720371396096,0/1,684,992,466,944,1,553,552,2035,648,20376,48128,48128,304319661504,30433440742792192,0/3,369,984,933,888,3,107,1104,4071,296,40752,96256,96256,608639323008,60866881485584384,0/6,739,969,867,776,6,214,2208,8142,592,81504,192512,192512,1217278646016,121733762971168768,0/13,479,939,735,552,12,428,4416,16284,1184,163008,385024,385024,2434557292032,243467525942337536,0/26,959,879,471,104,24,856,8832,32568,2368,326016,770048,770048,4869114584064,486935051884675072,0/53,919,758,942,208,49,713,17664,65136,4736,652032,1540096,1540096,9738229168128,973870103769350144,0/107,839,517,884,416,99,426,35328,130272,9472,1304064,3080192,3080192,19476458336256,1947740207538700288,0/215,679,035,768,838,198,852,70656,260544,18944,2608128,6160384,6160384,38952916672512,3895480415077400576,0/431,358,071,536,1,777,404,131,312,52,104,51680,51680,77905833345024,7790960830154801152,0/862,716,143,072,3,554,808,262,624,104,209,103360,103360,155811666690048,15582121660308602304,0/1,725,432,286,144,7,108,1616,525,248,208,408720,408720,311623333380096,31164243320617204608,0/3,450,864,572,288,14,216,3232,1050,496,416,817440,817440,623246666760192,62328486641234409216,0/6,901,728,114,576,28,432,6464,2100,992,832,1634880,1634880,1246493333520384,124656973282468818432,0/13,803,456,229,152,56,864,12928,4200,1984,1664,3269760,3269760,2492986667040768,24931

Figure 4 Illumination pattern [29].

[illegible]

8. List of defect detection and classification methods

[illegible]

(1) 凡在本市行政区域内，凡从事生产、经营活动的法人、其他经济组织、个体工商户、自然人，均应当依照本办法的规定，向所在地工商行政管理机关申请领取营业执照。









































[illegible]

9. Comparative evaluation of defect detection systems

[illegible]

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	

[illegible][illegible]

9.1 Pre-processing

$\{ \mathbf{a}_i \}_{i=1}^n$ is a linearly independent set in \mathbb{R}^n . Let $\mathbf{a}_i = (a_{i1}, a_{i2}, \dots, a_{in})$. Then \mathbf{a}_i is a linear combination of \mathbf{a}_j if and only if $\mathbf{a}_i = \sum_{j=1}^n c_j \mathbf{a}_j$ for some scalars c_j . This is equivalent to the system of equations $\sum_{j=1}^n c_j a_{ij} = a_{ii}$ for $i=1, 2, \dots, n$. This system has a non-trivial solution if and only if the determinant of the matrix (a_{ij}) is zero. Since \mathbf{a}_i is a linear combination of \mathbf{a}_j , the determinant of (a_{ij}) is zero. Conversely, if the determinant of (a_{ij}) is zero, then the system of equations has a non-trivial solution, and \mathbf{a}_i is a linear combination of \mathbf{a}_j .

[illegible]

5,44,5,5.

[illegible]

Table 2 List of defect classification methods

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

Wavelet transform is a mathematical tool that can be used to analyze signals at different scales. It is particularly useful for analyzing signals that contain features at multiple scales, such as cracks in steel surfaces. The wavelet transform can be used to extract features from the steel surface images that are characteristic of cracks. These features can then be used to classify the defects in the steel surface.

9.2 Spatial domain-based methods

Spatial domain-based methods are a class of methods that analyze the steel surface images in the spatial domain. These methods typically involve extracting features from the images that are characteristic of cracks, such as the length, width, and orientation of the cracks. These features can then be used to classify the defects in the steel surface. One of the most common spatial domain-based methods is the edge detection method. This method involves detecting the edges of the cracks in the steel surface images. The edges of the cracks are typically detected using the Sobel operator or the Canny operator. Once the edges of the cracks have been detected, they can be used to extract features such as the length, width, and orientation of the cracks. These features can then be used to classify the defects in the steel surface. Another common spatial domain-based method is the region-based method. This method involves dividing the steel surface images into regions and analyzing the features of each region. The features of each region are typically analyzed using statistical methods, such as the mean, standard deviation, and variance. These features can then be used to classify the defects in the steel surface. The region-based method is particularly useful for analyzing defects that are localized in the steel surface, such as pits and inclusions. In addition to edge detection and region-based methods, there are many other spatial domain-based methods that can be used to analyze steel surface images. These methods typically involve extracting features from the images that are characteristic of cracks, such as the length, width, and orientation of the cracks. These features can then be used to classify the defects in the steel surface.

Table 3 Comparison of defect detection systems



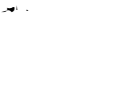










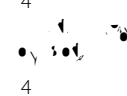




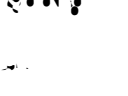


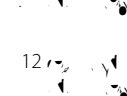



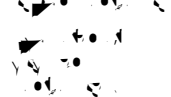
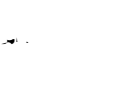


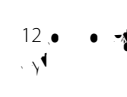




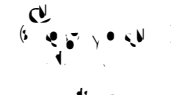







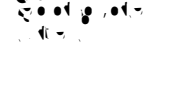












Paper	Method		Type of defects	Sample size	Features	Detection accuracy (%)	Resolution (across × along)	Speed of steel object (m/s)	Real-time operation	Remark
	Detection	Classification								
67 - 				7,110 	7 	94.08				
29 - 				1,764 	4 	87.1	0.57 0.5			
38 				1,568 	4 	97.6				
64 				220 	12 	97.8	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)







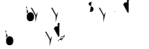









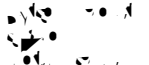



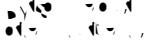


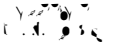

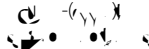



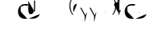

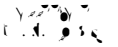





61 - 			175 (73%)	95.42	18.5		
58 - 			408	93.88 100	4.6		
60 - 			400 7 9	97.5	18		
44 - 			2,444 42	96.9	0.3	18.5	
2 - 			1,226	94.4	100		
5 - 			2,080 14	91.83	0.5	18	
75 - 			6	100	0.5	18	
59 - 			663 12	85.82 89	15		

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 /s (36.6 /s)	
70			24	1,432	3 9	93.8	1 1	20 /s	
36				1,084	24	83.5			
62				485	54	84 93			
32				255	4	98.75		10 15 /s	
31				2,300	9	97, 82	0.37		
76				15 20		85 95		6 /s	
26				196		95.5	0.17 1.25	1,400 /s (23 /s)	
89				135	17	68 96		5 /s	
63				2,300	10	97.9	0.37		
43				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)

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 2% ...
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 12 ...
 5 ...
 5% ... 4% ...
 2 (...) ... 0 (...) ...
 24 ... 2 ...
 (...) ...
 2 (...) ... 4 (...) ...
 (32 - 32) ...
 (...) ...
 (...) ...

1. $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$
 2. $\frac{1}{2} \times \frac{1}{4} = \frac{1}{8}$
 3. $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$
 4. $\frac{1}{4} \times \frac{1}{8} = \frac{1}{32}$
 5. $\frac{1}{8} \times \frac{1}{8} = \frac{1}{64}$
 6. $\frac{1}{8} \times \frac{1}{16} = \frac{1}{128}$
 7. $\frac{1}{16} \times \frac{1}{16} = \frac{1}{256}$
 8. $\frac{1}{16} \times \frac{1}{32} = \frac{1}{512}$
 9. $\frac{1}{32} \times \frac{1}{32} = \frac{1}{1024}$
 10. $\frac{1}{32} \times \frac{1}{64} = \frac{1}{2048}$
 11. $\frac{1}{64} \times \frac{1}{64} = \frac{1}{4096}$
 12. $\frac{1}{64} \times \frac{1}{128} = \frac{1}{8192}$
 13. $\frac{1}{128} \times \frac{1}{128} = \frac{1}{16384}$
 14. $\frac{1}{128} \times \frac{1}{256} = \frac{1}{32768}$
 15. $\frac{1}{256} \times \frac{1}{256} = \frac{1}{65536}$
 16. $\frac{1}{256} \times \frac{1}{512} = \frac{1}{131072}$
 17. $\frac{1}{512} \times \frac{1}{512} = \frac{1}{262144}$
 18. $\frac{1}{512} \times \frac{1}{1024} = \frac{1}{524288}$
 19. $\frac{1}{1024} \times \frac{1}{1024} = \frac{1}{1048576}$
 20. $\frac{1}{1024} \times \frac{1}{2048} = \frac{1}{2097152}$
 21. $\frac{1}{2048} \times \frac{1}{2048} = \frac{1}{4194304}$
 22. $\frac{1}{2048} \times \frac{1}{4096} = \frac{1}{8388608}$
 23. $\frac{1}{4096} \times \frac{1}{4096} = \frac{1}{16777216}$
 24. $\frac{1}{4096} \times \frac{1}{8192} = \frac{1}{33554432}$
 25. $\frac{1}{8192} \times \frac{1}{8192} = \frac{1}{67108864}$
 26. $\frac{1}{8192} \times \frac{1}{16384} = \frac{1}{134217728}$
 27. $\frac{1}{16384} \times \frac{1}{16384} = \frac{1}{268435456}$
 28. $\frac{1}{16384} \times \frac{1}{32768} = \frac{1}{536870912}$
 29. $\frac{1}{32768} \times \frac{1}{32768} = \frac{1}{1073741824}$
 30. $\frac{1}{32768} \times \frac{1}{65536} = \frac{1}{2147483648}$
 31. $\frac{1}{65536} \times \frac{1}{65536} = \frac{1}{4294967296}$
 32. $\frac{1}{65536} \times \frac{1}{131072} = \frac{1}{8589934592}$
 33. $\frac{1}{131072} \times \frac{1}{131072} = \frac{1}{17179869184}$
 34. $\frac{1}{131072} \times \frac{1}{262144} = \frac{1}{34359738368}$
 35. $\frac{1}{262144} \times \frac{1}{262144} = \frac{1}{68719476736}$
 36. $\frac{1}{262144} \times \frac{1}{524288} = \frac{1}{137438953472}$
 37. $\frac{1}{524288} \times \frac{1}{524288} = \frac{1}{274877906944}$
 38. $\frac{1}{524288} \times \frac{1}{1048576} = \frac{1}{549755813888}$
 39. $\frac{1}{1048576} \times \frac{1}{1048576} = \frac{1}{1099511627776}$
 40. $\frac{1}{1048576} \times \frac{1}{2097152} = \frac{1}{2199023255552}$
 41. $\frac{1}{2097152} \times \frac{1}{2097152} = \frac{1}{4398046511104}$
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 56. $\frac{1}{268435456} \times \frac{1}{536870912} = \frac{1}{144115188075855872}$
 57. $\frac{1}{536870912} \times \frac{1}{536870912} = \frac{1}{288230376151711744}$
 58. $\frac{1}{536870912} \times \frac{1}{1073741824} = \frac{1}{576460752303423488}$
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 60. $\frac{1}{1073741824} \times \frac{1}{2147483648} = \frac{1}{2305843009213693952}$
 61. $\frac{1}{2147483648} \times \frac{1}{2147483648} = \frac{1}{4611686018427387904}$
 62. $\frac{1}{2147483648} \times \frac{1}{4294967296} = \frac{1}{9223372036854775808}$
 63. $\frac{1}{4294967296} \times \frac{1}{4294967296} = \frac{1}{18446744073709551616}$
 64. $\frac{1}{4294967296} \times \frac{1}{8589934592} = \frac{1}{36893488147419103232}$
 65. $\frac{1}{8589934592} \times \frac{1}{8589934592} = \frac{1}{73786976294838206464}$
 66. $\frac{1}{8589934592} \times \frac{1}{16777216} = \frac{1}{147573952589676412928}$
 67. $\frac{1}{16777216} \times \frac{1}{16777216} = \frac{1}{295147905179352825856}$
 68. $\frac{1}{16777216} \times \frac{1}{33554432} = \frac{1}{590295810358705651712}$
 69. $\frac{1}{33554432} \times \frac{1}{33554432} = \frac{1}{1180591620717411303424}$
 70. $\frac{1}{33554432} \times \frac{1}{67108864} = \frac{1}{2361183241434822606848}$
 71. $\frac{1}{67108864} \times \frac{1}{67108864} = \frac{1}{4722366482869645213696}$
 72. $\frac{1}{67108864} \times \frac{1}{134217728} = \frac{1}{9444732965739290427392}$
 73. $\frac{1}{134217728} \times \frac{1}{$

[illegible]

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 - 95.5) - 44.5
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

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- 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

- 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.

Figure 1 displays a 4x4 grid of scatter plots showing the relationship between the number of children (N) and the number of children who are not in the sample (Nc). The plots are arranged in a 4x4 grid, with the top row showing N vs Nc for N=1, 2, 3, 4 and the bottom row showing N vs Nc for N=5, 6, 7, 8. The plots show a general trend of decreasing Nc as N increases, with some scatter.

• 3 •

835215, 2, 721302,

1. N. N. & N. N. (1997). 30(1), 3-10
2. An Intelligent Real-time Vision System for Surface Defect Detection (1997), 17-25
3. Detection of Steel Defect Using the Image Processing Algorithms (2008), 125-127
4. (2013)
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