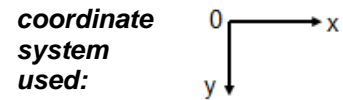


Results for the Indentation Image Group “SteelUnpolished” including error analysis with respect to dates manually determined by Expert A

(Indentation vertices manually obtained by Expert A: see file “SteelUnpolished_ExpertA_Table.pdf”)

60 indentation images obtained from Steel-316 samples, 640x480 pixels, acquired by a CCD camera implemented in the microdurometer Mitutoyo model HM-124, 50-fold magnification, indenter load 500 gf. University of Veracruz at Boca del Rio / CINVESTAV-IPN at Mexico City, Mexico, 2018.

Each image presents exactly one indentation footprint of rhombic form. The table contains the x,y-coordinates of its four vertices determined by the method reported in the article “Indentation image analysis for Vickers hardness testing” (Domínguez-Nicolás and Wiederhold), submitted to IEEE-CEE Conference 2018, June 2018.



The results reported below were obtained by the **method option which includes standard histogram equalization** as first processing step, followed by morphological filtering with a diamond of radius 10. The implementation was made within the software environment DIAS (shareware, University Jena, Germany), where gray images are integer valued between 0 and 255, most image processing operations are performed within integer arithmetic, and where the Harris-Stephen corner detector was applied directly to the binary (morphologically filtered) image (without previous Gaussian filter), using parameter $k=0.04$ and threshold 80 for the corner response function. An equivalent implementation is being developed in MATLAB.

image number	coordinates (x,y) of vertices North(N), East(E), South(S), West(W) obtained by the automatic method	error (Euclidean distance in pixels) with respect to the true vertex manually determined by Expert A	rhombus diagonal lengths in pixels calculated automatically and from Expert A true dates	absolute error (in pixels) and relative error of mean diagonal length versus true dates due to Expert A
1	N = (289,71) E = (425,204) S = (294,329) W = (155,209)	12.0000 3.6055 0.0000 2.2361 average: 4.4604	N-S: 258.0484 W-E: 270.0463 mean: 264.0474 true mean: 259.0484	absolute error: 4.9999 relative error: 1.9298 %
2	N = (362,117) E = (506,251) S = (368,371) W = (238,260)	11.7047 8.6023 2.8284 11.04536 average: 8.5452	N-S: 254.0709 W-E: 268.1511 mean: 261.1110 true mean: 250.5252	absolute error: 10.5852 relative error: 4.2254 %
3	N = (369,4) E = (493,216) S = (354,349) W = (211,218) Using radius 11 for morphol. filter avoids N-error: N = (350,90) E = (493,216)	89.2693 0.0000 1.0000 1.0000 average: 22.8173 wrong segmentation in N due to inhomog. illumination. 1.4142 0.0000	N-S: 345.3259 W-E: 282.0071 mean: 313.6665 true mean: 270.0278 N-S: 259.0309 W-E: 282.0160	absolute error: 43.6387 relative error: 16.1608 % absolute error: 0.4956

	S = (354,349) W = (211,219)	1.0000 1.4142 average: 0.9571	mean: 270.5234 true mean: 270.0278	relative error: 0.18353 %
4	N = (266,67) E = (406,198) S = (268,327) W = (123,199)	6.7082 2.2361 1.0000 2.0000 average: 2.9861	N-S: 260.0077 W-E: 283.0018 mean: 271.5047 true mean: 270.5192	absolute error: 0.9855 relative error: 0.3643 %
5	N = (289,76) E = (426,206) S = (289,334) W = (155,214)	6.7082 1.000 5.0000 2.2361 average: 3.7361	N-S: 258.0000 W-E: 271.1181 mean: 264.5590 true mean: 259.5242	absolute error: 5.0349 relative error: 1.9400 %
6	N = (391,58) E = (536,180) S = (400,305) W = (268,185)	6.4031 1.0000 3.0000 1.4142 average: 2.9543	N-S: 247.1639 W-E: 268.0466 mean: 257.6053 true mean: 252.5412	absolute error: 5.0641 relative error: 2.0052 %
7	N = (330,65) E = (479,205) S = (332,348) W = (180,207)	4.2426 2.0000 1.0000 6.0828 average: 3.3313	N-S: 283.0071 W-E: 299.0067 mean: 291.0069 true mean: 287.0300	absolute error: 3.9768 relative error: 1.3855 %
8	N = (291,75) E = (457,211) S = (295,353) W = (140,213)	1.4142 1.4142 1.4142 1.0000 average: 1.3107	N-S: 278.0288 W-E: 317.0063 mean: 297.5175 true mean: 297.5215	absolute error: 0.0039 relative error: 0.0013 %
9	N = (272,90) E = (432,229) S = (273,375) W = (116,234)	3.1623 2.0000 3.1623 1.0000 average: 2.3311	N-S: 285.0018 W-E: 316.0396 mean: 300.5206 true mean: 297.5208	absolute error: 2.9999 relative error: 1.0083 %
10	N = (401,40) E = (510,140) S = (405,240) W = (297,144)	1.4142 2.0000 0.0000 1.0000 average: 1.1036	N-S: 200.0400 W-E: 213.0376 mean: 206.5388 true mean: 206.5534	absolute error: 0.0146 relative error: 0.0071 %
11	N = (286,65) E = (439,202) S = (288,339) W = (140,203)	1.4142 2.0000 1.4142 2.0000 average: 1.7071	N-S: 274.0073 W-E: 299.0017 mean: 286.5045 true mean: 284.5223	absolute error: 1.9822 relative error: 0.6967 %
12	N = (325,48) E = (485,187) S = (328,336) W = (173,188)	2.0000 3.0000 4.1231 1.4142 average: 2.6343	N-S: 288.0156 W-E: 312.0016 mean: 300.0086 true mean: 297.5218	absolute error: 2.4868 relative error: 0.8358 %

13	N = (323,115) E = (448,224) S = (324,337) W = (208,224)	2.0000 2.2361 1.0000 1.0000 average: 1.5590	N-S: 288.0156 W-E: 312.0016 mean: 231.0011 true mean: 230.5094	absolute error: 0.4917 relative error: 0.2133 %
14	N = (401,103) E = (519,210) S = (404,316) W = (289,211)	1.4142 2.0000 2.2361 1.4142 average: 1.7661	N-S: 213.0211 W-E: 230.0022 mean: 221.5116 true mean: 220.0091	absolute error: 1.5025 relative error: 0.6829 %
15	N = (400,85) E = (520,191) S = (402,302) W = (287,192)	1.4142 2.2361 3.0000 1.4142 average: 2.0161	N-S: 217.0092 W-E: 233.0022 mean: 225.0057 true mean: 224.0427	absolute error: 0.9629 relative error: 0.4298 %
16	N = (351,66) E = (464,167) S = (354,274) W = (243,167)	1.0000 0.0000 1.0000 1.0000 average: 0.7500	N-S: 208.0216 W-E: 221.0000 mean: 214.5108 true mean: 215.0059	absolute error: 0.4951 relative error: 0.2303 %
17	N = (351,56) E = (473,161) S = (353,271) W = (235,165)	2.2361 2.2361 2.2361 1.0000 average: 1.9270	N-S: 215.0093 W-E: 238.0336 mean: 226.5215 true mean: 223.5202	absolute error: 3.0013 relative error: 1.3427 %
18	N = (405,104) E = (520,210) S = (405,315) W = (290,209)	2.0000 2.2361 2.0000 1.4142 average: 1.9126	N-S: 211.0000 W-E: 230.0022 mean: 220.5011 true mean: 219.5091	absolute error: 0.9919 relative error: 0.4519 %
19	N = (288,102) E = (404,206) S = (291,309) W = (178,208)	0.0000 3.0000 2.0000 1.4142 average: 1.6036	N-S: 207.0217 W-E: 226.0088 mean: 216.5153 true mean: 217.5121	absolute error: 0.9968 relative error: 0.4583 %
20	N = (397,98) E = (525,202) S = (402,314) W = (283,207)	2.0000 2.2361 2.8284 1.0000 average: 2.0161	N-S: 216.0579 W-E: 242.0516 mean: 229.0548 true mean: 227.0552	absolute error: 1.9995 relative error: 0.8806 %
21	N = (337,99) E = (458,207) S = (339,316) W = (221,210)	1.4142 1.4142 2.0000 1.0000 average: 1.4571	N-S: 217.0092 W-E: 237.0190 mean: 227.0141 true mean: 226.0199	absolute error: 0.9942 relative error: 0.4398 %

22	N = (400,125) E = (519,231) S = (402,334) W = (288,229)	4.0000 3.6056 2.0000 3.0000 average: 3.1514	N-S: 209.0096 W-E: 231.0087 mean: 220.0091 true mean: 217.5060	absolute error: 2.5031 relative error: 1.1508 %
23	N = (399,108) E = (516,210) S = (399,317) W = (284,212)	1.4142 1.0000 2.2361 1.4142 average: 1.5161	N-S: 209.0000 W-E: 232.0086 mean: 220.5043 true mean: 219.5120	absolute error: 0.9924 relative error: 0.4521 %
24	N = (401,105) E = (519,213) S = (402,319) W = (286,214)	3.1623 3.1623 1.4142 1.0000 average: 2.1847	N-S: 214.0023 W-E: 233.0022 mean: 223.5022 true mean: 220.5150	absolute error: 2.9872 relative error: 1.3546 %
25	N = (313,106) E = (459,242) S = (314,376) W = (169,246)	2.2361 1.0000 1.0000 1.4142 average: 1.4126	N-S: 270.0018 W-E: 290.0276 mean: 280.0147 true mean: 279.5226	absolute error: 0.4921 relative error: 0.1760 %
26	N = (288,79) E = (451,221) S = (292,376) W = (134,225)	2.2361 1.4142 22.0227 1.0000 average: 6.6682 Problem: wrong segmentation due to artifact adhered to S.	N-S: 297.0269 W-E: 317.0252 mean: 307.0261 true mean: 294.5273	absolute error: 12.4988 relative error: 4.2437 %
27	N = (370,51) E = (534,194) S = (373,340) W = (214,195)	2.2361 3.1623 2.0000 2.2361 average: 2.4086	N-S: 289.0156 W-E: 320.0016 mean: 304.5086 true mean: 300.0043	absolute error: 4.5043 relative error: 1.5014 %
28	N = (379,72) E = (528,207) S = (382,342) W = (228,209)	1.4142 1.4142 0.0000 1.4142 average: 1.0607	N-S: 270.0167 W-E: 300.0067 mean: 285.0117 true mean: 284.5070	absolute error: 0.5046 relative error: 0.1774 %
29	N = (350,133) E = (467,237) S = (351,342) W = (237,239)	1.0000 0.0000 2.0000 1.4142 average: 1.1036	N-S: 209.0024 W-E: 230.0087 mean: 219.5055 true mean: 218.5206	absolute error: 0.9849 relative error: 0.4507 %
30	N = (299,131) E = (415,239) S = (301,346) W = (176,239)	1.4142 1.0000 2.0000 0.0000 average: 1.1036	N-S: 215.0093 W-E: 239.0000 mean: 227.0046 true mean: 226.5302	absolute error: 0.4744 relative error: 0.2094 %

31	N = (343,101) E = (460,213) S = (339,327) W = (219,215)	5.0000 3.0000 2.2361 2.2361 average: 3.1180	N-S: 226.0354 W-E: 241.0083 mean: 233.5218 true mean: 230.0011	absolute error: 3.5207 relative error: 1.5307 %
32	N = (346,100) E = (472,210) S = (353,316) W = (227,209)	2.2361 2.2361 2.0000 2.2361 average: 2.1770	N-S: 216.1134 W-E: 245.0020 mean: 230.5577 true mean: 228.0228	absolute error: 2.5349 relative error: 1.1117 %
33	N = (381,103) E = (496,211) S = (384,315) W = (268,213)	1.0000 1.0000 2.2361 1.4142 average: 1.4126	N-S: 212.0212 W-E: 228.0088 mean: 220.0150 true mean: 219.0426	absolute error: 0.9724 relative error: 0.4439 %
34	N = (311,151) E = (434,261) S = (316,371) W = (191,262)	2.2361 1.0000 3.1623 1.0000 average: 1.8496	N-S: 220.0568 W-E: 243.0021 mean: 231.5294 true mean: 229.0226	absolute error: 2.5068 relative error: 1.0946 %
35	N = (303,120) E = (419,226) S = (303,333) W = (184,225)	3.1623 2.2361 2.8284 1.4142 average: 2.4102	N-S: 213.0000 W-E: 235.0021 mean: 224.0011 true mean: 222.5054	absolute error: 1.4956 relative error: 0.6722 %
36	N = (358,89) E = (475,193) S = (354,294) W = (242,194)	2.2361 1.4142 5.3852 1.0000 average: 2.5089	N-S: 205.0390 W-E: 233.0022 mean: 219.0206 true mean: 218.5152	absolute error: 0.5053 relative error: 0.2313 %
37	N = (361,117) E = (474,221) S = (366,317) W = (258,220)	5.3852 4.1231 1.4142 1.0000 average: 2.9806	N-S: 200.0625 W-E: 216.0023 mean: 208.0324 true mean: 208.0215	absolute error: 0.0109 relative error: 0.0052 %
38	N = (363,126) E = (475,220) S = (363,327) W = (256,230)	2.0000 2.2361 4.1231 6.4031 average: 3.6906	N-S: 201.0000 W-E: 219.2282 mean: 210.1141 true mean: 205.5390	absolute error: 4.5751 relative error: 2.2259 %
39	N = (387,147) E = (493,247) S = (385,339) W = (275,245)	5.3852 3.1623 1.0000 2.2361 average: 2.9459	N-S: 192.0104 W-E: 218.0092 mean: 205.0098 true mean: 208.0161	absolute error: 3.0063 relative error: 1.4452 %

40	N = (355,116) E = (464,221) S = (358,326) W = (245,230)	13.1530 4.2426 3.1623 5.6569 average: 6.5537 Illumination problem.	N-S: 201.0214 W-E: 219.1848 mean: 214.6031 true mean: 203.0253	absolute error: 11.5778 relative error: 5.7026 %
41	N = (299,144) E = (421,252) S = (305,364) W = (181,256)	2.2361 1.0000 2.8284 2.2361 average: 2.0751	N-S: 220.0818 W-E: 240.0333 mean: 230.0576 true mean: 229.0140	absolute error: 1.0436 relative error: 0.4557 %
42	N = (365,126) E = (490,237) S = (368,350) W = (244,236)	2.2361 2.0000 2.2361 1.0000 average: 1.8680	N-S: 224.0201 W-E: 246.0020 mean: 235.0111 true mean: 234.5407	absolute error: 0.4703 relative error: 0.2005 %
43	N = (328,122) E = (454,227) S = (329,342) W = (209,233)	1.0000 2.2361 3.1623 2.2361 average: 2.1486	N-S: 220.9923 W-E: 245.9735 mean: 232.5379 true mean: 231.5103	absolute error: 1.0276 relative error: 0.4438 %
44	N = (293,121) E = (411,229) S = (295,343) W = (172,233)	2.2361 2.0000 3.0000 3.1623 average: 2.5996	N-S: 222.0090 W-E: 239.0335 mean: 230.5212 true mean: 227.5198	absolute error: 3.0014 relative error: 1.3192 %
45	N = (336,135) E = (466,242) S = (341,350) W = (214,248)	2.2361 1.0000 1.0000 3.0000 average: 1.8090	N-S: 215.0581 W-E: 252.0714 mean: 233.5648 true mean: 232.5648	absolute error: 1.5101 relative error: 0.6508 %
46	N = (317,96) E = (442,208) S = (319,321) W = (199,210)	1.0000 1.0000 0.0000 2.2361 average: 1.0590	N-S: 225.0089 W-E: 243.0082 mean: 233.5648 true mean: 233.0138	absolute error: 0.9948 relative error: 0.4269 %
47	N = (309,75) E = (427,183) S = (306,289) W = (185,185)	4.4721 1.4142 3.1623 2.2361 average: 2.8212	N-S: 214.0210 W-E: 242.0083 mean: 228.0146 true mean: 225.0357	absolute error: 2.9790 relative error: 1.3238 %
48	N = (347,60) E = (511,204) S = (365,370) W = (191,208)	4.2426 4.2426 23.8537 4.000 average: 9.0848 Problem: dark artifact adhered to S-vertex.	N-S: 310.5221 W-E: 320.0250 mean: 315.2736 true mean: 300.0043	absolute error: 15.2693 relative error: 5.0897 %

49	N = (362,108) E = (530,253) S = (367,398) W = (201,253)	3.0000 3.6056 1.4142 3.1623 average: 2.7956	N-S: 290.0431 W-E: 329.0000 mean: 309.5216 true mean: 304.5148	absolute error: 5.0068 relative error: 1.6442 %
50	N = (323,58) E = (487,202) S = (329,352) W = (165,206)	0.0000 4.4721 4.4721 1.0000 average: 2.4861	N-S: 294.0612 W-E: 322.0248 mean: 308.0430 true mean: 304.0523	absolute error: 3.9907 relative error: 1.3125 %
51	N = (359,105) E = (526,257) S = (364,408) W = (197,258)	4.1231 2.2361 4.4721 2.2361 average: 3.2668	N-S: 303.0412 W-E: 329.0015 mean: 316.0214 true mean: 312.0106	absolute error: 4.0108 relative error: 1.2855 %
52	N = (337,77) E = (499,222) S = (347,362) W = (187,221)	2.8284 3.1623 3.6056 3.0000 average: 3.1491	N-S: 285.1754 W-E: 312.0016 mean: 298.5885 true mean: 293.5222	absolute error: 5.0662 relative error: 1.7260 %
53	N = (295,75) E = (459,223) S = (303,367) W = (139,226)	1.0000 2.0000 2.2361 1.0000 average: 1.5590	N-S: 292.1096 W-E: 320.0141 mean: 306.0618 true mean: 305.0987	absolute error: 0.9631 relative error: 0.3157 %
54	N = (376,59) E = (544,203) S = (383,349) W = (220,204)	3.1623 2.8284 2.8284 1.4142 average: 2.5583	N-S: 290.0845 W-E: 324.0015 mean: 307.0430 true mean: 304.0066	absolute error: 3.0364 relative error: 0.9988 %
55	N = (403,100) E = (573,241) S = (410,389) W = (251,244)	1.4142 4.0000 1.4142 1.4142 average: 2.0607	N-S: 289.0848 W-E: 322.0140 mean: 305.5494 true mean: 302.0458	absolute error: 3.5035 relative error: 1.1599 %
56	N = (364,89) E = (537,239) S = (365,381) W = (208,239)	3.1623 2.8284 6.3246 1.0000 average: 3.3288	N-S: 292.0017 W-E: 329.0000 mean: 310.5009 true mean: 310.0205	absolute error: 0.4803 relative error: 0.1549 %
57	N = (331,98) E = (495,242) S = (342,389) W = (179,244)	5.0000 3.1623 1.4142 5.0990 average: 3.6689	N-S: 291.2078 W-E: 316.0063 mean: 303.6071 true mean: 297.5443	absolute error: 6.0627 relative error: 2.0376 %

58	N = (237,36) E = (434,240) S = (282,388) W = (119,245) Using radius 14 for morphol. filter avoids N-error: N = (275,95) E = (434,240) S = (282,388) W = (120,245)	74.3303 2.2361 3.0000 2.0000 average: 20.3916 Illumination problem. 4.2426 2.2361 3.0000 2.2361 average: 2.9287	N-S: 354.8648 W-E: 315.0397 mean: 334.9522 true mean: 300.0267 N-S: 293.0836 W-E: 314.0398 mean: 303.5617 true mean: 300.0267	absolute error: 34.9255 relative error: 11.6408 % absolute error: 3.5350 relative error: 1.1782 %
59	N = (271,72) E = (429,216) S = (278,356) W = (119,215)	2.2361 2.2361 2.2361 2.2361 average: 2.2361	N-S: 284.0862 W-E: 310.0016 mean: 297.0439 true mean: 294.0353	absolute error: 3.0087 relative error: 1.0232 %
60	N = (346,77) E = (516,226) S = (357,376) W = (187,232)	5.0990 2.8284 5.0990 0.0000 average: 3.2566	N-S: 299.2023 W-E: 329.0547 mean: 314.1285 true mean: 311.0334	absolute error: 3.0951 relative error: 0.9951 %

Outliers: images where the result of some vertex is highly wrong (caused by illumination):

3 relative error 16.1608 % N-vertex error 89.2693 pixel units

58 relative error 11.6408 % S-vertex error 74.3303 pixel units

(Both these images, when treated with slightly larger radius for morphological filtering, could be analyzed with excellent results, see table above.)

Images where the result of some vertex is somewhat wrong:

2 relative error 4.2254 % errors in vertices $N > 11, E > 8, W > 11$ (caused by artifacts adhered)

26 relative error 4.2437 % S-vertex error 22.0227 pixel units (caused by artifact adhered)

40 relative error 5.7026 % N-vertex error 13.1530 pixel units (caused by illumination)

48 relative error 5.0897 % S-vertex error 23.8537 pixel units (caused by artifact adhered)

For all other images, the maximal relative error is 2.2259 %.

Error-Histogram of all 60 images:

relative error larger than 6 % (outliers): 2 images (3: 16.16%, 58: 11.64%)

relative error between 4 and 6 %: 4 images (2, 26, 40, 48)

relative error between 1 and 2.3 %: 20 images (1, 5, 6, 7, 9, 17, 22, 24, 27, 31, 32, 34, 38, 39, 44, 47, 49, 50, 51, 52, 55, 57, 59)

relative error less than 1 %: 31 images (4, 8, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 23, 25, 28, 29, 30, 33, 35, 36, 37, 41, 42, 43, 45, 46, 53, 54, 56, 60)

relative error less than 2.3 %: 51 out of 60 images = 85%