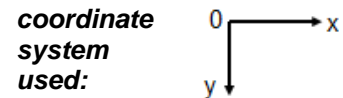


Results for the Indentation Image Group “Deformed” including error analysis with respect to dates manually determined by Expert A

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

50 indentation images obtained from Hafnium samples, 640x480 pixels, acquired by a CCD camera implemented in the microdurometer Mitutoyo model HM-124, 50-fold magnification, indenter load 300 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.

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 to the binary segmented image, without previous Gaussian filter, using parameter $k=0.04$ and threshold 100 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 = (299,70) E = (463,212) S = (303,370) W = (144,214)	2.0000 2.2361 2.0000 1.4142 average: 1.9126	N-S: 300.0267 W-E: 319.0063 mean: 309.5165 true mean: 306.0262	absolute error: 3.4903 relative error: 1.1405 %
2	N = (314,106) E = (424,210) S = (314,310) W = (205,212)	2.2361 2.2361 1.4142 1.0000 average: 1.7216	N-S: 204.0000 W-E: 219.0091 mean: 211.5046 true mean: 212.5291	absolute error: 1.0246 relative error: 0.4821 %
3	N = (338,72) E = (456,177) S = (341,284) W = (229,176)	1.0000 2.0000 1.0000 4.4721 average: 2.1180	N-S: 212.0212 W-E: 227.0022 mean: 219.5117 true mean: 219.5118	absolute error: 0.00009144 relative error: 0.00004144 %

4	N = (308,86) E = (428,196) S = (313,301) W = (197,196)	1.0000 2.8284 1.0000 1.0000 average: 1.4571	N-S: 215.0581 W-E: 231.0000 mean: 223.0291 true mean: 220.5337	absolute error: 2.4953 relative error: 1.1315 %
5	N = (403,129) E = (522,235) S = (404,347) W = (284,239)	2.0000 2.0000 0.0000 1.0000 average: 1.2500	N-S: 218.0023 W-E: 238.0336 mean: 228.0180 true mean: 228.5145	absolute error: 0.4966 relative error: 0.2173 %
6	N = (401,136) E = (517,243) S = (406,348) W = (296,244)	1.4142 3.6056 2.2361 3.1623 average: 2.6045	N-S: 212.0590 W-E: 221.0023 mean: 216.5306 true mean: 215.5209	absolute error: 1.0097 relative error: 0.4685 %
7	N = (332,84) E = (497,226) S = (335,378) W = (178,225)	1.4142 2.0000 3.1623 2.2361 average: 2.2031	N-S: 294.0153 W-E: 319.0016 mean: 306.5084 true mean: 302.5216	absolute error: 3.9869 relative error: 1.3179 %
8	N = (265,121) E = (383,228) S = (265,333) W = (154,225)	1.0000 3.0000 2.2361 3.6056 average: 2.4604	N-S: 212.0000 W-E: 229.0197 mean: 220.5098 true mean: 219.0111	absolute error: 1.4987 relative error: 0.6843 %
9	N = (405,164) E = (522,270) S = (405,378) W = (293,272)	1.0000 2.8284 1.4142 4.4721 average: 2.4287	N-S: 214.0000 W-E: 229.0087 mean: 221.5044 true mean: 222.0090	absolute error: 0.5047 relative error: 0.2273 %
10	N = (404,134) E = (521,241) S = (404,345) W = (291,241)	2.2361 2.2361 1.4142 0.0000 average: 1.4716	N-S: 211.0000 W-E: 230.0000 mean: 220.5000 true mean: 218.5092	absolute error: 1.9908 relative error: 0.9111 %
11	N = (401,105) E = (519,213) S = (402,319) W = (286,214)	1.4142 2.2361 1.4142 1.0000 average: 1.5161	N-S: 214.0023 W-E: 233.0022 mean: 223.5022 true mean: 222.0149	absolute error: 1.4873 relative error: 0.6699 %
12	N = (378,133) E = (493,234) S = (382,344) W = (270,238)	0.0000 1.4142 2.2361 1.4142 average: 1.2661	N-S: 211.0379 W-E: 223.0359 mean: 217.0369 true mean: 215.0289	absolute error: 2.0080 relative error: 0.9338 %

13	N = (400,95) E = (518,200) S = (403,308) W = (288,200)	1.0000 3.1623 2.0000 1.4142 average: 1.8941	N-S: 213.0211 W-E: 230.0000 mean: 221.5106 true mean: 219.5233	absolute error: 1.9872 relative error: 0.9052 %
14	N = (320,92) E = (439,201) S = (323,306) W = (204,202)	1.4142 2.8284 1.4142 1.4142 average: 1.7678	N-S: 214.0210 W-E: 235.0021 mean: 224.5116 true mean: 223.0149	absolute error: 1.4967 relative error: 0.6711 %
15	N = (405,104) E = (520,210) S = (405,315) W = (290,209)	2.2361 2.2361 1.0000 2.2361 average: 1.9270	N-S: 211.0000 W-E: 230.0022 mean: 220.5011 true mean: 220.0091	absolute error: 0.4920 relative error: 0.2236 %
16	N = (289,71) E = (425,204) S = (294,329) W = (155,209)	12.0000 5.0990 2.0000 4.0000 average: 5.7748	N-S: 258.0484 W-E: 270.0463 mean: 264.0474 true mean: 261.5288	absolute error: 2.5185 relative error: 0.9630 %
17	N = (313,115) E = (429,220) S = (313,332) W = (194,223)	1.0000 1.4142 2.2361 1.4142 average: 1.5161	N-S: 217.0000 W-E: 235.0192 mean: 226.0096 true mean: 223.5108	absolute error: 2.4988 relative error: 1.1180 %
18	N = (327,93) E = (446,203) S = (329,315) W = (212,204)	1.0000 3.1623 1.0000 2.0000 average: 1.7906	N-S: 222.0090 W-E: 234.0021 mean: 228.0021 true mean: 226.0275	absolute error: 1.9781 relative error: 0.8752 %
19	N = (351,66) E = (464,167) S = (354,274) W = (243,167)	1.0000 1.0000 1.0000 2.0000 average: 1.2500	N-S: 208.0216 W-E: 221.0000 mean: 228.0021 true mean: 213.5094	absolute error: 1.0014 relative error: 0.4690 %
20	N = (342,85) E = (464,191) S = (346,302) W = (233,193)	2.0000 1.0000 1.0000 1.0000 average: 1.2500	N-S: 217.0387 W-E: 231.0087 mean: 224.0228 true mean: 224.5089	absolute error: 0.4862 relative error: 0.2165 %
21	N = (398,78) E = (521,183) S = (406,288) W = (285,185)	6.7082 3.1623 2.8284 1.0000 average: 3.4247	N-S: 210.1523 W-E: 236.0085 mean: 223.0804 true mean: 217.5778	absolute error: 5.5026 relative error: 2.5290 %

22	N = (309,90) E = (425,195) S = (313,299) W = (199,196)	2.2361 2.0000 2.2361 1.4142 average: 1.9716	N-S: 209.0383 W-E: 226.0022 mean: 217.5202 true mean: 217.0237	absolute error: 0.4965 relative error: 0.2288 %
23	N = (295,119) E = (412,224) S = (297,331) W = (182,227)	1.4142 2.2361 1.4142 2.2361 average: 1.8251	N-S: 212.0094 W-E: 230.0196 mean: 221.0145 true mean: 221.5090	absolute error: 0.4946 relative error: 0.2233 %
24	N = (394,72) E = (523,182) S = (397,296) W = (278,183)	1.4142 1.4142 2.8284 1.0000 average: 1.6642	N-S: 224.0201 W-E: 245.0020 mean: 234.5111 true mean: 232.5273	absolute error: 1.9838 relative error: 0.8531 %
25	N = (299,70) E = (463,212) S = (303,370) W = (144,214)	1.0000 2.8284 1.0000 0.0000 average: 1.2071	N-S: 300.0267 W-E: 319.0063 mean: 309.5165 true mean: 307.5260	absolute error: 1.9904 relative error: 0.6472 %
26	N = (316,84) E = (483,239) S = (318,385) W = (158,239)	3.6056 1.0000 1.0000 0.0000 average: 1.4014	N-S: 301.0066 W-E: 325.0000 mean: 313.0033 true mean: 311.5134	absolute error: 1.4899 relative error: 0.4783 %
27	N = (417,116) E = (583,253) S = (421,394) W = (271,257)	2.0000 2.0000 1.4142 1.0000 average: 1.6036	N-S: 278.0288 W-E: 312.0256 mean: 295.0272 true mean: 295.0138	absolute error: 0.0134 relative error: 0.0046 %
28	N = (343,101) E = (460,213) S = (339,327) W = (219,215)	5.0000 2.0000 2.8284 1.0000 average: 2.7071	N-S: 226.0354 W-E: 241.0083 mean: 233.5218 true mean: 231.0056	absolute error: 2.5163 relative error: 1.0893 %
29	N = (303,120) E = (419,226) S = (303,333) W = (184,225)	2.0000 3.1623 3.1623 1.0000 average: 2.3311	N-S: 213.0000 W-E: 235.0021 mean: 224.0011 true mean: 223.5054	absolute error: 0.4956 relative error: 0.2218 %
30	same as Option 1 N = (361,117) E = (474,221) S = (366,317) W = (258,220)	4.4721 4.1231 1.4142 1.4142 average: 2.8559	N-S: 200.0625 W-E: 216.0023 mean: 208.0324 true mean: 208.0214	absolute error: 0.0110 relative error: 0.0053 %

31	N = (363,126) E = (475,220) S = (363,327) W = (256,230)	1.4142 1.4142 5.3852 7.8102 average: 4.0060	N-S: 201.0000 W-E: 219.2282 mean: 210.1141 true mean: 205.5308	absolute error: 4.5833 relative error: 2.2300 %
32	N = (387,147) E = (493,247) S = (385,339) W = (275,245)	5.8310 3.1623 1.4142 7.0000 average: 4.3519	N-S: 192.0104 W-E: 218.0092 mean: 205.0098 true mean: 211.0215	absolute error: 6.0117 relative error: 2.8489 %
33	N = (328,122) E = (454,227) S = (329,342) W = (209,233)	0.0000 2.0000 4.1231 2.0000 average: 2.0308	N-S: 220.0023 W-E: 245.0735 mean: 232.5379 true mean: 231.5208	absolute error: 1.0170 relative error: 0.4393 %
34	N = (374,30) E = (524,171) S = (377,311) W = (233,172)	1.4142 1.4142 2.2361 5.0990 average: 2.5409	N-S: 281.0160 W-E: 291.0017 mean: 286.0089 true mean: 286.5301	absolute error: 0.5301 relative error: 0.1819 %
35	N = (374,69) E = (523,203) S = (373,351) W = (232,206)	1.4142 1.4142 13.0384 4.0000 average: 4.9667	N-S: 282.0018 W-E: 291.0155 mean: 286.5086 true mean: 282.0144	absolute error: 4.4942 relative error: 1.5936 %
36	N = (373,24) E = (525,160) S = (379,298) W = (232,164)	10000 2.2361 2.2361 3.6056 average: 2.2694	N-S: 274.0657 W-E: 293.0273 mean: 283.5465 true mean: 282.0486	absolute error: 1.4979 relative error: 0.5311 %
37	N = (375,16) E = (535,154) S = (380,296) W = (225,158)	1.4142 1.0000 4.1231 1.0000 average: 1.8843	N-S: 280.0446 W-E: 310.0258 mean: 295.0352 true mean: 292.0300	absolute error: 3.0052 relative error: 1.0291 %
38	N = (372,21) E = (519,158) S = (379,291) W = (228,160)	0.0000 2.0000 1.4142 2.0000 average: 1.3536	N-S: 270.0907 W-E: 291.0069 mean: 280.5488 true mean: 282.0368	absolute error: 1.4880 relative error: 0.5276 %
39	N = (370,61) E = (529,199) S = (376,334) W = (230,200)	2.8284 1.0000 3.1623 3.1623 average: 2.5382	N-S: 273.0659 W-E: 299.0017 mean: 286.0338 true mean: 285.0308	absolute error: 1.0030 relative error: 0.3519 %

40	N = (374,30) E = (531,173) S = (378,314) W = (222,175)	3.1623 2.2361 3.1623 1.0000 average: 2.3902	N-S: 284.0282 W-E: 309.0065 mean: 296.5173 true mean: 293.0397	absolute error: 3.4776 relative error: 1.1868 %
41	N = (372,43) E = (525,180) S = (377,317) W = (225,184)	1.4142 2.2361 2.0000 3.0000 average: 2.1626	N-S: 274.0456 W-E: 300.0267 mean: 287.0361 true mean: 286.0355	absolute error: 1.0006 relative error: 0.3498 %
42	N = (372,21) E = (517,161) S = (370,306) W = (230,160)	3.0000 2.8284 11.4018 5.0000 average: 5.5576	N-S: 285.0070 W-E: 287.0017 mean: 286.0044 true mean: 280.0148	absolute error: 5.9896 relative error: 2.1390 %
43	N = (366,84) E = (515,219) S = (373,360) W = (225,232)	10.1980 4.2426 2.2361 8.4853 average: 6.2905	N-S: 276.0888 W-E: 290.2912 mean: 283.1900 true mean: 272.5483	absolute error: 10.6417 relative error: 3.9045 %
44	N = (379,72) E = (528,207) S = (382,342) W = (228,209)	0.0000 3.6056 1.4142 1.0000 average: 1.5049	N-S: 270.0167 W-E: 300.0067 mean: 285.0117 true mean: 283.0113	absolute error: 2.0004 relative error: 0.7068 %
45	N = (371,33) E = (528,168) S = (374,309) W = (223,172)	2.2361 0.0000 1.4142 0.0000 average: 0.9126	N-S: 276.0163 W-E: 305.0262 mean: 286.1259 true mean: 289.0140	absolute error: 1.5072 relative error: 0.5215 %
46	N = (319,68) E = (469,195) S = (321,326) W = (172,198)	2.0000 2.0000 3.1623 0.0000 average: 1.7906	N-S: 258.0078 W-E: 297.0152 mean: 277.5114 true mean: 274.0165	absolute error: 3.4949 relative error: 1.2754 %
47	same as Option 1 N = (340,67) E = (498,211) S = (342,355) W = (180,209)	3.1623 2.0000 0.0000 2.8284 average: 1.9977	N-S: 288.0069 W-E: 318.0063 mean: 303.0066 true mean: 300.5111	absolute error: 2.4956 relative error: 0.8304 %
48	N = (330,71) E = (468,191) S = (333,323) W = (195,194)	1.0000 1.0000 1.4142 0.0000 average: 0.8536	N-S: 252.0179 W-E: 273.0165 mean: 262.5172 true mean: 261.0243	absolute error: 1.4929 relative error: 0.5719 %

49	N = (323,78) E = (459,200) S = (326,326) W = (188,201)	4.1231 2.0000 2.2361 1.0000 average: 2.3398	N-S: 248.0181 W-E: 271.0019 mean: 259.5100 true mean: 257.0518	absolute error: 2.4582 relative error: 0.9563 %
50	N = (335,69) E = (473,196) S = (339,316) W = (200,197)	2.0000 2.2361 1.4142 1.4142 average: 1.7661	N-S: 247.0324 W-E: 273.0018 mean: 260.0171 true mean: 258.5293	absolute error: 1.4878 relative error: 0.5755 %

Relative Error Histogram of the 50 images:

relative error between 2 and 4 %: 5 images (21, 31, 32, 42, 43)
relative error between 1 and 2 %: 9 images (1, 4, 7, 17, 28, 35, 37, 40, 46)
relative error less than 1 %: 36 images
(2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 22, 23, 24, 25, 26, 27, 29, 30, 33, 34, 36, 38, 39, 41, 44, 45, 47, 48, 49, 50)
relative error less than or equal 2 %: 45 images = 90 % of 50