FOS ONBOARD TARGET ACQUISITION TESTS

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I. Introduction

Onboard (or Mode II) target acquisition refers to a set of methods for acquiring and centering targets without real-time intervention. The ultimate aim of each target acquisition method is to accurately center the target in one of the small science apertures. The four onboard target acquisition strategies are:

1. Binary search: a target is located in the 4.3" aperture by stepping the diode array until the star is determined to be located on the edge of the array.
2. Peak-up: one or more raster scans are made of the target region with a small aperture in place. The position where the maximum count rate is observed is determined to be the position of the target.
3. Peak-down: is the same as a Peak-up target acquisition except that the target is determined to be the point where a minimum count rate is observed.
4. Firmware: the diode array scans the 4.3" aperture and the internal microprocessor filters the image to determine the position of targets within the aperture.

Each of these target acquisition strategies has their own features, strengths and weaknesses. Detailed descriptions and strategies can be found in the FOS target acquisition handbook. Here we report the results of five target acquisition tests designed to verify the operation and accuracy of the different target acquisition strategies.

Proposal 2195 (and its successor 3123), "Combined Mode II Target Acquisition" verifies all four target strategies on a single bright star. Proposal 1314 (Faint Object Target Acquisition) verifies Firmware on a single faint star and Binary search on a field of four faint quasar images. Proposal 1428 (and its successor 3137) "Blind Offset Target Acquisition" test the ability of the telescope to acquire one target and perform a slew to another nearby object. Finally, proposal 1427 "WFC Assisted Target Acquisition" tests a fifth target acquisition strategy involving a real-time target acquisition with the Wide Field Planetary Camera (WFC) followed by a telescope slew to place the star in the FOS aperture.

In the next section we discuss in detail the steps carried out in each of these proposals. The following section presents the results of the tests in tabular form along with an overall discussion and comments on target acquisition strategies.

II. Description of Individual Tests

Proposal 2195: Combined Mode II Target Acquisition.

The aim of this test is to verify all four on-board target acquisition techniques: Binary search, Firmware, Peak-up and Peak-down. A description of each of these techniques can be found in the HST Target Acquisition Handbook.

The proposal consists of four visits on each of the Red and Blue sides to the same target star (star 13 in NGC 188). Each visit consists of four individual tests starting with a Binary search test, followed by Firmware, Peak-up and finally Peak-down.

1. Binary search: The star is acquired in the 4.3 arcsecond target acquisition aperture and an ACQIMAGE is taken to verify the initial position of the star. A Binary search acquisition is then carried out and another ACQIMAGE is taken to verify the final position of the star in the aperture. This should be at the center of the aperture (pixel 48.5,32.5). Finally the 1.0 arcsecond aperture is inserted and another ACQIMAGE is taken to verify how well the star is centered within the smaller aperture.
2. Firmware: After the Binary search test, the guide stars are reacquired and the target is reacquired in the target acquisition aperture independently of the results of the previous test. An initial ACQIMAGE is taken to verify the position of the star in the aperture. Two Firmware acquisitions are successively carried out. The first is a coarse Firmware designed to approximately center the star in the aperture. The second is a fine Firmware to more accurately center the star. An ACQIMAGE is taken to verify the final position of the star.
3. Peak-up: The star is reacquired in the target acquisition aperture independently of the results of the previous test and an initial ACQIMAGE is taken to verify the position of the star in the aperture. An initial coarse Peak-up using the 1.0 arcsecond aperture and a step size of 0.7 arcseconds is performed. This Peak-up performs a 6×6 raster scan of the entire target acquisition aperture and slews the telescope to the pointing which yielded the maximum number of counts. After the initial Peak-up, an ACQIMAGE is taken to verify the position of the star in the aperture. Next, a finer Peak-up is carried out using the 0.3 arcsecond aperture and step sizes of 0.2 arcseconds. This Peak-up scans only the inner part of the aperture and slews the telescope to the pointing which yields the maximum count rate. The second Peak-up is immediately followed by a finer 5×5 Peak-up using the 0.3 arcsecond aperture and a step size of 0.05 arcseconds. The smaller step size is supposed to yield a more accurate final pointing. Finally the target acquisition aperture replaces the 0.3 arcsecond aperture and an ACQIMAGE is taken to verify the final pointing of the star.
4. Peak-down: The star is reacquired in the target acquisition aperture independently of the results of the previous test and an initial ACQIMAGE is taken to verify the position of the star in the aperture. A Binary search step is performed to center the star in the aperture and another ACQIMAGE is taken to verify the position of the

star. The Peak-down part of the test consists of a 1x11 raster scan across the star in the x direction only, with the large occulting bar aperture in place. The aim is that when the star is fully occulted by the bar, there will be a minimum in the count-rate during the scan. Thus the Peak-down test slews the telescope to the pointing which yields the minimum count-rate and the star should be properly occulted by the bar. Finally the target acquisition aperture replaces the occulting bar and an ACQIMAGE is taken to verify the final position of the star.

Proposal 3123: Revised Mode II Target acquisition:

The high failure rate of the tests in 2195 necessitated a repeat of the test with appropriate modifications to avoid the causes of previous failures. Proposal 3123 is the revised mode II target acquisition test. The basic structure of 3123 is the same as that of 2195 but there are modifications which came about as a result of our improved understanding of the telescope's performance gleaned from our experience with 2195. The major modifications are:

a) Because of the poor initial pointing of the telescope at this early stage in SV, it is not at all certain that the initial guide star acquisition places the star in the target acquisition aperture. We typically find pointing errors of several arcseconds. To avoid this problem we perform a "big Peak-up" after each guide star acquisition and before the rest of the test is carried out. The big Peak-up scans a region of 8.6×8.6 arcseconds with the target acquisition aperture in place, and the telescope is then slewed to the pointing with maximum count-rate. This ensures that the star is in the target acquisition aperture at the begining of the test.

b) Exposure times in all tests and the threshold count-rate in the binary search test is updated to take into account the shaped of the aberrated point-spread function which was discovered after launch.

c) Extra ACQIMAGES are included in the Peak-up so that the pointing after each individual step of the test can be verified.

d) The magnetic shielding on the Red side of the FOS has been found to be inadequate to shield the detector from the Earth's magnetic field. As a result, the image of the star on the photocathode appears to move during an orbit. The motion has an amplitude of 2 pixels and can thus significantly affect Binary search and Firmware target acquisition. Peak-up and Peak-down acquisitions are not affected by this problem because the image of the aperture on the photocathode moves in the same way as the image of the star, so the count-rate through the aperture at any particular pointing is unaffected. In an attempt to offset the effects of image motion on the Binary search and Firmware target acquisitions, a final TALED acquisition is added to each of these tests. With the 0.3 arcsec aperture in place, the target acquisition LED (TALED) illuminates the photocathode and a binary search or Firmware acquisition is carried out on the image of the illuminated 0.3 arcsec aperture. The telescope then slews to offset the effects of the image motion. Because the star acquisition and the TALED acquisition are not performed simultaneously this step is not perfect compensation for the image motion, but we employ it to determine if it can improve the target acquisition.

e) To facilitate scheduling, the requirement that the four parts of each visit be performed *en bloc* is relaxed.

f) The ACQIMAGEs taken through the 1 arcsec aperture are removed.

Hence the four parts of the test now comprise:

1. Binary search: big Peak-up followed by ACQIMAGE, binary search acquisition, ACQIMAGE, TALED Binary search acquisition, final ACQIMAGE.
2. Peak-up: big Peak-up followed by ACQIMAGE, Peak-up through 1.0 arcsec aperture, ACQIMAGE, Peak-up through 0.3 arcsec aperture, ACQIMAGE, fine Peak-up through 0.3 arcsec aperture, final ACQIMAGE.
3. Firmware: big Peak-up followed by ACQIMAGE, coarse Firmware, fine Firmware, ACQIMAGE, TALED Firmware acquisition, final ACQIMAGE.
4. Peak-down: big Peak-up followed by ACQIMAGE, binary search acquisition ACQIMAGE, 1x11 Peak-down scan, final ACQIMAGE.

Proposal 1314: Faint Object Target Acquisition

This test is designed to determine the performance of Firmware and binary search target acquisition on objects which are faint or in complicated fields. The Firmware tests are carried out on a faint isolated star in NGC 188. This part of the test comprises a big Peak-up to ensure the star is in the target acquisition aperture, followed by an ACQIMAGE to verify the initial position of the star in the aperture. A coarse and a fine Firmware acquisition are then performed and the final position of the star (near the center of the aperture) is verified by taking a final ACQIMAGE.

The Binary search part of the test is carried out on the gravitationally lensed quasar PG1115+080. This quasar has four images within 2 arcseconds of each other. The two brightest images (components A and A') lie within 0.5 arcseconds of each other while the fainter images (components B and C) lie further out. The aim of the Binary search test is to acquire the second brightest image of the four. After guide-star acquisition a big Peak-up is performed to place the star in the target acquisition aperture. An ACQIMAGE is taken to verify the initial pointing and a Binary search is performed to center the brightest component in the target acquisition aperture. Then an offset slew is performed to point the telescope at the center of the four images and another ACQIMAGE is taken to verify the pointing. A second Binary search acquisition centers the second brightest component in the target acquisition aperture and a final ACQIMAGE is taken to verify the accuracy of the final pointing.

Proposals 1428 & 3137: Blind Offset Target Acquisition.

This test verifies the ability of the FOS to acquire an initial target and then perform a blind offset to a second target. Such a strategy is useful, for example, in acquiring a galaxy nucleus by first acquiring a nearby foreground star and then offsetting to the ultimate target. The test is performed on a close pair of stars in NGC 188. The exposure sequence for 1428 is:

1. After guide star acquisition, take an ACQIMAGE to verify the initial position of the star in the acquisition aperture.
2. Perform a Binary search acquisition on the star.
3. Take an ACQIMAGE to verify the final position of the star.
4. Perform an offset slew of RA = -9.352" and DEC = -7.72" to the second star and take an ACQIMAGE to verify the final pointing of the telescope.

Proposal 1428 failed because of the poor pointing performance of HST at that time. The proposal was modified by performing a big Peak-up after each guide star acquisition to ensure that the initial target is in the target acquisition aperture. The test is then performed as in 1428. The modified proposal is proposal number 3137.

Proposal 1427: WFC Assisted Target Acquisition.

This test verifies the ability to acquire a target in real time using the Wide Field Camera (WFC) and then offset the telescope pointing so the target is centered in the FOS aperture. The exposure sequence is:

1. Acquire a target in real-time using the Wide Field Camera. The observer selects the target in the WFC image and the telescope is slewed so as to place the star in the center of the WFC chip. Another slew is performed to place the star in the FOS target acquisition aperture.
2. An ACQIMAGE is taken to verify the position of the star in the FOS target acquisition aperture.
3. A Binary search acquisition is performed to center the star in the FOS aperture.
4. The telescope slews to place the star back in the WFC chip and a WFC image is taken to verify the final position of the star.

III. Results & Comments

Results from all of the tests are given in the accompanying tables. Table 1 presents the results from proposal 3123 "Combined Mode II Target Acquisition." Table 1a presents the results of all the successful Peak-up acquisitions. Column 1 lists the observation sequence identification, Columns 2 and 3 lists the (x, y) pixel coordinates of the centroid of the star image (convolved with the diode point-spread-function) in the initial telescope pointing following guide-star acquisition. All the results presented here which refer to target positions within an ACQIMAGE have been derived from the raw ACQIMAGE because of the poor quality of the deconvolved ACQIMAGES. Experience shows that, where a reliable measurement can be made in the deconvolved ACQIMAGES, the target positions agree with positions derived from the raw ACQIMAGES. The target positions are measured using the IRAF task IMEXAMINE which employs a sophisticated and reliable centroiding algorithm. Columns 4 and 5 list the (x, y) pixel positions of the target after the first Peak-up sequence. Columns 6 and 7, and columns 8 and 9 list the target positions after the second and third Peak-up sequences respectively. Column 10 lists the detector employed in each visit (RD is the Red detector, BL is the Blue detector). At the bottom of the table are the mean pixel positions and the standard deviations. Given the small number statistics involved however, these numbers are only indicative of the true accuracy of the tests. Note that all numbers are in units of ACQIMAGE pixels which are 0.08" on a side.

Table 1b presents the results of the Binary search target acquisitions including those carried out as part of the Peak-down test. Column 1 lists the sequence identification, columns 2 and 3 list the pixel positions of the initial target position. Columns 4 and 5 lists the telescope slew (in detector coordinates) calculated by Binary search (in arcseconds). Columns 6 and 7 list the position of the target after the Binary search slew. Column 8 lists the number of steps which Binary search used to locate the target. Columns 9 and 10 list the final position of the target after the TALED acquisition. Column 11 lists the detector used.

Table 1c presents the results of the Firmware tests. Once again, column 1 lists the sequence identification and columns 2 and 3 list the initial position of the target. Columns 4 and 5 list the final target position after the coarse *and* the fine Firmware acquisition. Columns 6 and 7 list the target position after the TALED acquisition while column 8 lists the detector used.

Finally table 1d lists the results of the Peak-down target acquisition. Column 1 lists the sequence identification. Columns 2 and 3 list the initial target positions. Columns 4 and 5 list the target position after the initial Binary search step. Columns 6 and 7 list the target position after the Peak-down step.

A number of general conclusions can be drawn from these tests:

- **Binary search** is probably the primary acquisition strategy for the FOS because of its high accuracy and efficiency. The tests show that it converges usually in 6–7 steps and places the star roughly at pixel (48.5,32.5) as designed. The scatter for the

Binary search tests alone is small (~0.05") and quite acceptable for the 0.3" aperture. The additional step included in the revised mode II TA proposal (3123)—namely the TALED—shifts the target toward (51,32), but significantly increases the scatter and makes it unacceptable for the 0.3" aperture. The reason for the increased scatter after the TALED acquisition is unclear at this point. Another puzzle is that the accuracy of the Binary search performed as a part of the Peak-down tests is worse than that of the normal Binary search. The parameters specified for each acquisition are identical. We cannot say that there is any significant difference between the Binary search accuracy on the Red side and the Blue side. If the geomagnetically induced image motion is responsible for much of the scatter in the Binary search acquisitions then the Red side would be expected to be less accurate than the Blue side. Unfortunately, the number of tests in the sample is too small to draw strong statistical conclusions.

- **Peakup acquisition** sequences in general are as accurate as the Binary search. The second step of the test (0.3" aperture, 0.2" step) places the object at pixel position (51,32) with a small scatter of order of 0.05". The third step, although performed with a very fine step size of only 0.05", does not appear to improve the accuracy of the pointing. Both the pointing position (51,32) and scatter (~0.05") remain the same. We cannot say, however, that the third step does not provide a more accurate pointing because there may be significant spacecraft or image motion (*e.g.* jitter or geomagnetically induced image motion) between the end of the Peak-up sequence and the taking of the ACQIMAGE. Any such motion introduces error into our measurered target position.

- Results from Binary search and Peak-up tests show one major difference—Binary search places the object at (48.5,32.5) while Peak-up goes to (51,32). This is a difference of almost 0.25". This may be explained by the projected position of the 0.3" aperture lying at (51,32) and not at (48.5,32.5) as used in the Binary search software. This is supported by the results of the TALED Binary search acquisition which also places the target at (51,32). Furthermore, a large number of Binary search followed by Peak-up target acquisition sequences carried out in the Bahcall quasar survey show that the final Peak-up position is systematically offset from the Binary search position by approximately 0.1" in the x direction (Hartig, private communication). At this time, it appears that there is an x-base offset in the Binary search algorithm. A modification is currently being implemented.

- **Firmware** results show a large scatter in the final pointing. The degree of the scatter makes it unacceptable for acquiring a target into any of the FOS science apertures.

- **Peak-down** acquisitions place the object roughly at the expected position, but the scatter is almost as large as the scatter found in the Firmware tests. Part of the problem may be due to the lower accuracy of the Binary search step (not understood), but we don't have enough data to trace it. It is also found that the Peak-down sequence finds a very shallow minimum. This is undoubtedly because of the large amount of scattered light from the aberrated point-spread function which would reduce the expected accuracy of this target acquisition strategy.

the final pixel positions is (.123,0.066). We also find that the mean radial offset from the nominal position (48.5,32.5) is 1.52 pixels or 0.12". Columns 6 and 7 in table 3 list the pixel positions of the second target star immediately after the blind offset. Columns 8 and 9 list the difference between the blind offset target position and the initial Binary search target position. The data in these last two columns indicate the accuracy of the telescope slew across a distance on the order of 10". Note however, that these numbers also contain the errors due to spacecraft jitter and image motion between the time that the two ACQIMAGES were taken. The mean positional differences are not significantly different from zero, given their standard deviation, so we conclude that there is no evidence for a systematic offset from the target after the blind offset. The scatter in the target positions after the blind offset is significantly larger than the scatter after the first Binary search. Thus it appears that the blind offset introduces additional uncertainty in the final target position which is on the order of the uncertainty after a Binary search acquisition. This is supported by the fact that the mean radial offset between the target position before and after the blind offset is 1.64 pixels or 0.13". So we conclude that a blind offset does appear, on average, to slew the telescope to the correct position but it introduces additional uncertainty in the final target position amounting to a total uncertainty of around 2.5 pixels or 0.2". Thus some care may be required for blind offset acquisitions into FOS science apertures smaller than 0.5", but the accuracy is acceptable for the larger science apertures.

Finally, the WFC Assisted Target Acquisition (proposal 1427) was successful in both visits on the Blue side (the Red side visits were not carried out because of the success on the Blue side). In visit one, the initial WFC target acquisition and slew worked well, placing the target in the FOS target acquisition aperture approximately 0.7" from the center. The Binary search acquisition on this target was successful. The final slew back to the WFC placed that star within 0.1" of the intended WF-ALL position. The second visit on the Blue side met with similar success.

IV. Conclusions

In terms of accuracy, Binary Search and Peak-up are the preferred modes of target acquisition with the FOS. In these tests, each strategy has delivered an accuracy of around 0.1". Binary search is the most efficient method but it is subject to error from the geomagnetically induced image motion problem. For acquisitions requiring high pointing accuracy, a Binary search followed by a small one stage Peak-up may be considered. Peak-up target acquisition is potentially more accurate than Binary search (depending on the step size in the final stage), and is unaffected by image motion, but it is the least efficient of the onboard acquisition strategies. The peak-down results show that the technique is successful at centering a target behind an occulting bar. However, the large amount of scattered light makes this technique a lot less precise than it would be without the spherical aberration. The Firmware results show that it does not deliver sufficient pointing accuracy to be useful for target acquisition into the science apertures.

Offset target acquisition and acquisition of faint objects work well. The blind offset tests show that the spacecraft slew is correct, but there appears to be added uncertainty on the order of 0.1" in the final target position. Our experience with acquisition of faint objects in complex fields with Binary search shows that this technique can work, but the acquisition must be carefully planned.

Table 1: Summary of Proposal 3123: Revised Mode II Target Acquisition.

a) Successful Peakup acquisitions:

	Init. pointing		First step		Second step		Third step		
Y0G60701	54.34	29.79	50.72	35.89	51.12	31.70	51.58	32.45	RD
Y0G60301	68.05	30.56	48.16	29.54	50.67	31.74	50.19	32.68	BL
Y0G60F01	52.17	22.48	49.74	33.02	51.65	31.18	51.25	32.89	RD
Y0G60B01	50.65	30.05	47.5	34.27	50.03	32.10	50.16	32.14	BL
Mean	56.30	28.22	49.03	33.18	50.87	31.68	50.80	32.54	
Sdev	7.98	3.84	1.47	2.70	0.69	0.38	0.73	0.32	

b) Successful Binary Search tests:

	Init. pointing		Slew		Final pointing		Nsteps	After TALED		
Y0G60101	69.53	32.26	1.291	0.18	47.17	33.43	6	47.44	33.28	BL
Y0G60501	56.16	28.69	0.671	-0.20	47.77	31.99	9	54.03	29.58	RD
Y0G60D01	52.92	21.19	0.501	-0.98	46.91	32.61	7	52.28	33.06	RD
Y0G60901	50.87	29.68	0.361	-0.18	47.35	32.15	6	49.51	31.83	BL
Mean					47.30	32.55		50.82	31.94	
Sdev					0.36	0.65		2.92	1.70	

Binary search phase of peak-down tests:

Y0G60801	55.07	27.09	0.679	-0.31	47.68	30.63	8	RD
Y0G60401	69.22	32.98	1.707	0.17	48.1	33.28	6	BL
Y0G60G01	53.37	22.77	0.512	-0.89	46.59	32.45	6	RD
Y0G60C01	51.66	31.24	0	0	51.87	31.23	7	BL
Mean					48.56	31.90		
Sdev					2.30	1.19		

c) Successful Firmware tests:

	Init. pointing		Final pointing		After TALED		
Y0G60601	56.43	29.85	43.05	31.05	43.55	31.33	RD
Y0G60201	70.31	32.05	50.1	32.48	50.12	32.27	BL
Y0G60E01	53.63	22.35	43.35	33.22	52.45	34.14	RD
Y0G60A01	50.58	29.83	50.39	32.6	50.22	32.39	BL
Mean	57.74	28.52	46.72	32.34	49.09	32.53	
Sdev	8.72	4.24	4.07	0.92	3.84	1.17	

d) Successful peak-down tests:

	Init. pointing		After BS		After peak-down		
Y0G60801	55.07	27.09	47.68	30.63	46.20	33.27	RD
Y0G60401	69.22	32.98	48.10	33.28	48.24	31.46	BL
Y0G60G01	53.37	22.77	46.59	32.45	48.44	33.44	RD
Y0G60C01	51.66	31.24	51.87	31.23	52.12	31.91	BL
Mean	57.33	28.52	48.56	31.90	48.75	32.52	
Sdev	8.05	4.56	2.30	1.19	2.46	0.98	

Table 2: Summary of 1314: Faint Object Target Acquisition

Successful Firmware acquisitions on NGC 2287-5

	Initial pointing		Final pointing		
Y0J30103	35.99	29.81	42.86	32.02	RD
Y0J30203	68.13	34.38	50.37	31.73	BL
Y0J30401	46.72	42.89	48.28	32.2	BL
Y0J30601	44.45	43.01	48.27	32.9	BL
Y0J35501	56.01	37.03	43.54	35.87	RD
Mean			46.66	32.94	
Sdev			3.28	1.69	

Table 3: Summary of 3137: Revised Blind Offset Target Acquisition

Summary of Blind Offset Acquisition:

	Init. pointing		After BS		After offset		Difference	
Y0I80203	58.19	28.16	47.1	32.22	47.3	30.73	0.2	-1.49
Y0I80403	49.91	31.45	46.04	32.4	44.21	32.38	-1.83	-0.02
Y0I80103	63.13	25.63	48.04	33.24	49.24	31.7	1.2	-1.54
Y0I80303	38.79	31.95	45.89	31.95	44.96	31.07	-0.93	-0.88
Mean	52.51	29.30	46.77	32.45	46.43	31.47	-0.34	-0.98
Sdev	10.65	2.97	1.00	0.56	2.29	0.73	1.32	0.71