

HARP & ACSIS Commissioning Report No 2.

Version 1:
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Objective

Confirm pixel positions using total power scans of the Moon edge.

Data

Data obtained during HARP commissioning 20070204-05.

- 20070204
 - Scan 51 2x4800" azimuth scan across the Moon sampling 4" – reversal false
 - Scan 52 600" azimuth scan of Moon edge sampling 0.5"
 - Scan 56 600" elevation scan of Moon edge sampling 0.5"
- 20070205
 - Scan 27 2x4800" azimuth scan across the Moon sampling 4" – reversal true
 - Scan 28 600" elevation scan of Moon edge sampling 0.5"

The scanning was done using a tangent projection. Thus the scan are across the Moon and perpendicular to the Moon edge. The tangent point was the center of the Moon. The offset to the edge of the Moon causes negligible distortion of the scale. Further, receptor 1, 3 and 4 was not operational. Obviously, no positional information was obtained for these detectors.

Data Reduction

The data used is the raw total power reported by the IF system for each sub integration and detector as stored in the aips++ measurement set files. This data is not archived but available from the author. The data was extracted and then calibrated by averaging the sub-integrations on the loads and sky reference for each calibration in the data file. Then performing

$$\frac{TP_i - skyref}{amb - skyref} \cdot Tamb$$

The sky reference and ambient data was interpolated between calibrations if applicable. The calibration is not perfect in an absolute sense but does a good job on the relative calibration. The data was then plotted and the distance between the detectors along the scanning direction measured on the plots.

Measurements

Azimuth scans – separation between columns has been measured for each row. Each row of pixels will cross the Moon edge at the same point. Thus, Moon topography and edge curvature should not have an influence¹. Errors source are calibration, tracking and seeing variations. Calibration since

¹1km is about 0.5" at the Moons distance. Thus, Moon topography is on the edge of being important. Assuming the Moon is a sphere with radius of 900" the top and bottom row would cross the edge displaced by 1" compared to the two central rows.

crossing a selected power level will shift with the scaling. Seeing and tracking since there is a slight time delay between when each column crosses the Moon edge. For the edge scan there is 6 seconds delay between the receptor columns transverse the Moon edge. For the faster full Moon scans the delay is 0.75 seconds. As would be expected there is more variations in the slower edge scans. For the full Moon scans the pixel separations can be measured four times – the Moon was scanned twice in each observation and both edges were traversed. In the second full azimuth observation, scan 27 20070205, the data from the two transversals are identical.

Row4	R13	R14	R15	R16
Row3	R12	R11	R10	R09
Row2	R05	R06	R07	R08
Row1	R04	R03	R02	R01
	Col1	Col2	Col3	Col4

Table 1: Receptor, Row and Column definitions

	5-6	6-7	7-8	12-11	11-10	10-9	13-14	14-15	15-16
Scan51	30.4	30.4	30.4	31.8	30.8	31.8	32.5	31.8	33.2
	30.4	30.4	30.0	31.1	31.1	31.8	31.8	32.5	32.5
	30.8	30.0	31.1	31.1	31.8	31.8	31.8	32.5	31.8
	30.4	30.4	30.4	31.8	31.1	31.8	32.5	31.8	33.2
Scan52	30.3	30.3	30.0	31.2	31.2	30.6	31.9	32.2	31.2
Scan27	29.7	30.0	31.1	30.8	31.5	31.5	32.2	32.2	32.5
	29.7	30.0	31.1	30.8	31.5	31.5	32.2	32.2	32.5
	30.4	31.1	30.4	31.1	31.8	31.8	31.8	32.5	32.5
	30.4	31.1	30.4	31.1	31.8	31.8	31.8	32.5	32.5
Average	30.2	30.4	30.5	31.2	31.4	31.6	32.1	32.2	32.4
St. Dev.	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.6

Table 2: Horizontal separation between receptors

The variation in pixel separation between the rows is statistical significant using the standard deviation as a guide. The variation along each row is not significant using the same criteria. However, the systematic variations along each row do make the variation believable. Note that a shift in the position of the Moon edge, say due to seeing or tracking errors, can decrease on separation an increase another. The best way to decrease such correlated errors is to scan fast.

	5-12	12-13	6-11	11-14	2-7	7-10	10-15	8-9	9-16
Scan56	30.6	32.6	30.6	32.6	31.5	29.5	32.8	29.6	32.8
Scan28	30.9	31.4	31.6	32.1	27.5	31.2	33.1	31.4	32.8
Average	30.8	32.0	31.1	32.4	29.5	30.4	33.0	30.5	32.8
St. Dev.	0.2	0.8	0.7	0.4	2.8	1.2	0.2	1.3	0.0

Table 3: Vertical separation between receptors

As noted above the distance variability is larger in these slower edge scans. However, if we average the distance between row 2 and 3 (5-12, 6-11, 7-10, 8-9) we get 30.7” with a st. dev. of 0.8. Similar if we average the distance between row 3 and 4 (12-13, 11-14, 10-15, 9-16) we get 32.5” with a st. dev. of 0.5”. Thus, there is a barely significant difference in the distance between the rows.

In the Azimuth scans, columns of receptors will cross the Moon edge almost simultaneously. We do expect a 1" shift between the outer pixels and the two central receptors as discussed in footnote 1. This is taken into account the table 3.

Rows	Col 1		Col 2		Col 3			Col 4	
	3-2	4-2	3-2	4-2	1-2	3-2	4-2	3-2	4-2
Scan51	-1.3	-1.4	+0.0	+0.2	-2.2	+1.3	+2.3	+1.9	+4.2
...	-1.9	+0.1	-0.8	+1.6	-4.2	+0.8	+3.5	+1.6	+5.1
...	-0.5	-1.1	+0.5	+1.0	-2.5	+1.1	+2.6	+2.1	+4.7
...	-2.4	+0.2	-1.3	+1.6	-5.2	-0.8	+3.2	+0.0	+5.6
Scan27	-0.5	-2.2	+0.8	+0.2	-0.9	+1.6	+1.8	+1.9	+3.1
...	-1.0	-2.0	+0.3	+0.6	-1.8	+1.3	+2.0	+1.7	+3.5
...	-1.0	-2.7	+0.5	+0.2	-1.4	+1.3	+1.5	+2.1	+3.7
...	-0.8	-1.5	+0.5	+0.8	-1.1	+1.9	+2.4	+2.1	+3.5
Scan52	-0.8	-0.9	+0.5	+1.0	-2.7	+1.9	+2.9	+2.1	+4.2
Average	-1.1	-1.3	0.1	0.8	-2.4	1.0	2.5	1.7	4.2
St. Dev.	0.6	1.0	0.7	0.6	1.4	0.8	0.7	0.7	0.8

Table 3: Shift of receptors rightwards in a column with respect to the receptor in row 2.

Column 1 shears slightly to the left when going up the column, column 2 is straight within the errors while column 3 and 4 shifts increasingly to the right.

In the Elevations scans, rows of receptors will cross the Moon edge almost simultaneously. As before the expected 1" shift of the out her receptors with respect to the central receptors is taken into account in table 4.

Col	Row 2			Row 3			Row 4		
	1-2	3-2	4-2	1-2	3-2	4-2	1-2	3-2	4-2
Scan 56	1.5	-1.8	-2.5	1.0	-1.8	-3.8	1.0	-2.6	-3.2
Scan 27	3.2	-2.1	-2.6	2.7	-2.4	-2.7	1.4	-2.4	-2.8
Average	2.3	-2.0	-2.6	1.8	-2.1	-3.2	1.2	-2.5	-3.0
St. Dev.	1.2	0.2	0.1	1.2	0.4	0.8	0.3	0.1	0.3

Table 4: Shift of receptors upwards in a row with respect to the receptor in column 2.

Each row tends to be high to the left and dip down at the right end.

Results

The data above shows that the pixel separation increases from bottom to the top both vertically and horizontally. In addition, the rows are lower to the right end and the columns tilts to the right at the right end. To summaries the result the measured pixel differences was fitted to a second order model using Excel's solve function.

$$\left. \begin{aligned} x(p, q) &= a_1 \cdot p + a_2 \cdot p^2 + a_3 \cdot q + a_4 \cdot q^2 + a_5 \cdot p \cdot q \\ y(p, q) &= b_1 \cdot p + b_2 \cdot p^2 + b_3 \cdot q + b_4 \cdot q^2 + b_5 \cdot p \cdot q \end{aligned} \right\} (p, q) \in (1, 2, 3, 4)$$

$$\begin{aligned} a_1 &= 28.133 & b_1 &= -2.436 \\ a_2 &= 0.083 & b_2 &= 0.128 \\ a_3 &= -0.407 & b_3 &= 26.302 \\ a_4 &= -0.203 & b_4 &= 0.884 \\ a_5 &= 0.928 & b_5 &= 0.034 \end{aligned}$$

The fit has 10 free parameters that are fitted to the 36 separations measured. Thus, there are 26 degrees of freedom. The fit produces excellent results – the greatest deviation from the data is 0.8” with the bulk of the separations fitted much better. The reduced sum of squares is 27 if a typical error of 0.4” is used. A histogram for the errors is shown in figure 1 with 0.2” bins centered on the given values. Using larger average errors makes the reduced sum of squares be below expect values.

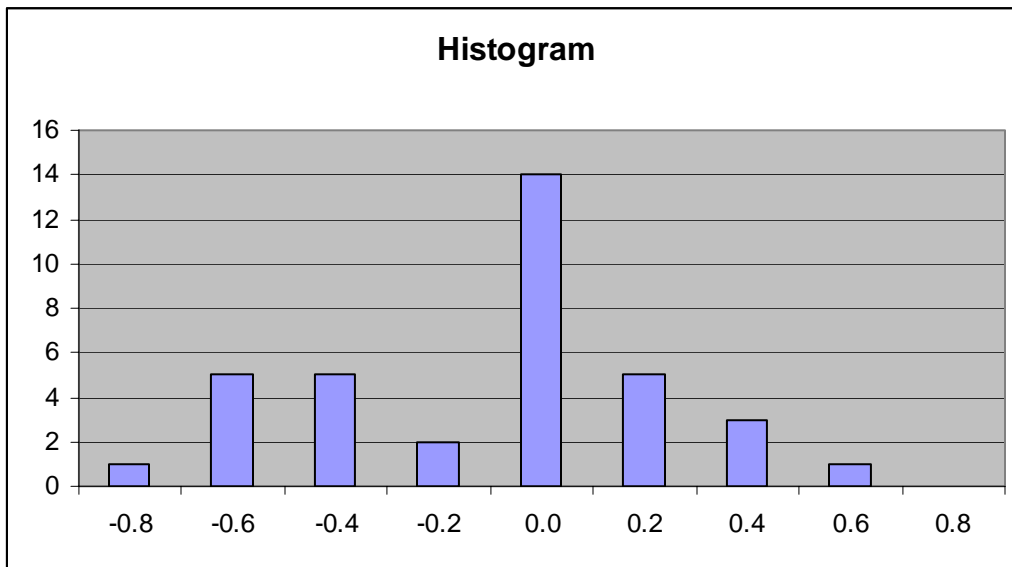


Figure 1: Error histogram

If the sum of the x and y positions are forced to zero the following pixel offsets are obtained. The same information is also shown in figure 2. The positions for receptors 1, 3 and 4 are predictions from the data since these detectors not were available in February.

-47.2, +49.7	-15.1, +47.8	+17.2, +46.1	+49.6, +44.7
-46.3, +17.2	-15.1, +15.2	+16.2, +13.5	+47.7, +12.1
-45.8, -13.6	-15.5, -15.6	+14.9, -17.3	+45.4, -18.7
-45.7, -42.6	-16.4, -44.6	+13.1, -46.3	+42.7, -47.8

Table 5: Measured Pixel offsets. The values with a gray background were not measured.

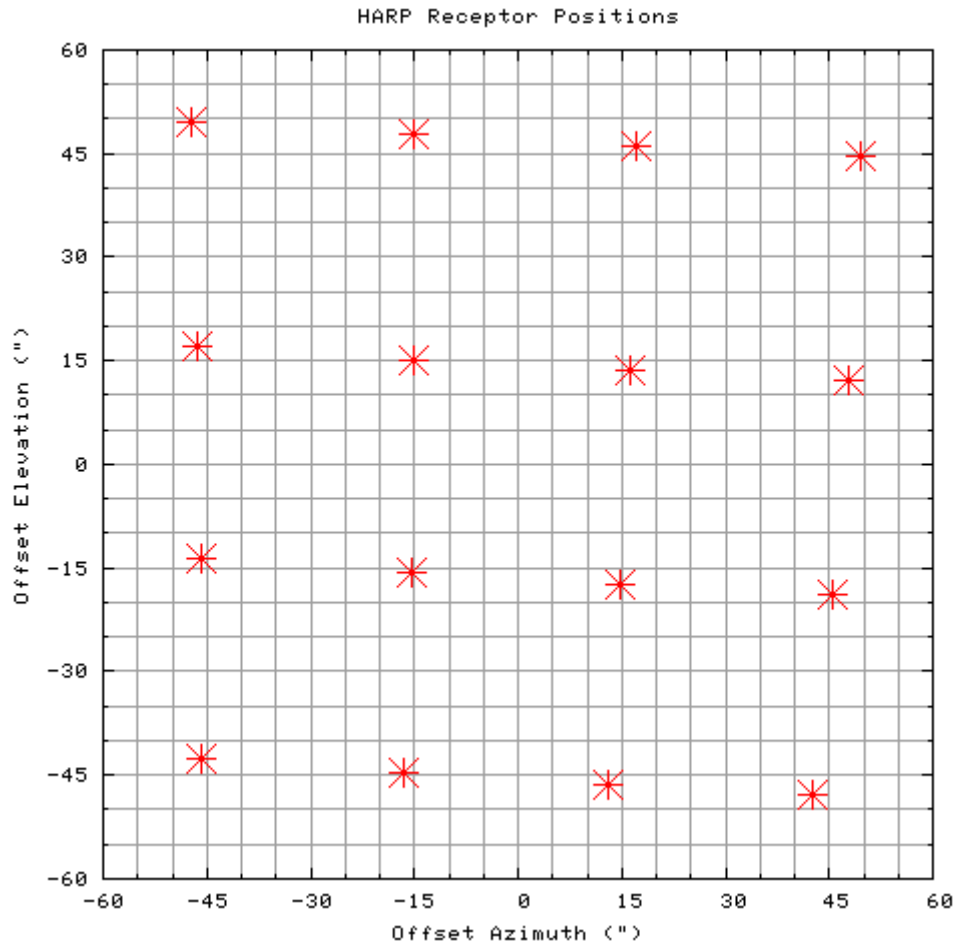


Figure 2: Measured HARP pixel positions. Note the positions for receptor 1, 3 and 4 are predictions.

Discussion:

The data gives a consistent picture which fits well to a simple model. Judging from the standard deviation from the measurements and the reduced sum of squares the error are of order $\pm 0.5''$. However, since there might be correlated errors, systematic effects and the array distortion perhaps is larger than expected it would be prudent to assume the accuracy is less than the formal. Thus, I would not assign a better accuracy than $\pm 1''$ from the results above. Given the distortion appears optical there is also the issue if the distortions depends on the K-mirror angle. The current observations were obtained at elevations of 60 degrees (20070204) and 30 degrees (20070205). The results for these elevations are consistent within the errors. These result needs to be confirmed.